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**Defining the Relationship Between  
Human Error Classes and Technology  
Intervention Strategies**

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## **Abstract**

One of the main factors in all aviation accidents is human error. The NASA Aviation Safety Program (AvSP), therefore, has identified several human-factors safety technologies to address this issue. Some technologies directly address human error either by attempting to reduce the occurrence of errors or by mitigating the negative consequences of errors. However, new technologies and system changes may also introduce new error opportunities or even induce different types of errors. Consequently, a thorough understanding of the relationship between error classes and technology “fixes” is crucial for the evaluation of intervention strategies outlined in the AvSP, so that resources can be effectively directed to maximize the benefit to flight safety. The purpose of the present project, therefore, was to examine the repositories of human factors data to identify the possible relationship between different error class and technology intervention strategies. The first phase of the project, which is summarized here, involved the development of prototype data structures or matrices that map errors onto “fixes” (and vice versa), with the hope of facilitating the development of standards for evaluating safety products. Possible follow-on phases of this project are also discussed. These additional efforts include a thorough and detailed review of the literature to fill in the data matrix and the construction of a complete database and standards checklists.

## **Part 1: Introduction and Problem Statement**

The NASA Aviation Safety Program (AvSP) has defined several products that will potentially modify airline and/or ATC operations, enhance aircraft systems, and improve the identification of potential hazardous situations within the National Airspace System (NAS). Each product has a human component. However, while some address human error directly others do so only indirectly. Some attempt to eliminate the occurrence of errors altogether whereas others look to reduce the negative consequences of these errors. Consequently, there is a need to develop standards for evaluating the potential safety benefit of each of these intervention products so that resources can be effectively invested to produce the biggest benefit to flight safety.

The purpose of this project was to help define the relationship between human error and technological interventions. Specifically, this project examined the repositories of human error data to identify factors known to either directly or indirectly affect the occurrence and consequences of human error in aviation and sought to develop a taxonomy of technologies that would allow a mapping between different technologies and human error. The ultimate goal was to develop a set of standards for evaluating or measuring the potential benefits of new human error “fixes.”

It must be acknowledged and understood, however, how difficult such an endeavor is, given the wide variety of technologies and equally varied circumstances for their use, as well as the abundance of human factors data that currently exists in the literature. Therefore, our approach has been to develop a framework for summarizing the overabundance of data in a manner that best suits the specific questions that users might have. Indeed, there are two types of questions that could be asked when considering the issue of human error and intervention strategies. These are:

1. Given a new technology is to be implemented, which specific types or classes of human error will most likely be affected?
2. Given that a certain type or class of human error has been identified as a major safety problem (e.g., decision errors), what kinds of technologies will most likely help in alleviating the problem?

Obviously, each question has a different emphasis and each serves a different function. Therefore, the human error data will need to be organized in a manner that allows both types of questions to be answered. In essence, the human error classes will need to be mapped onto the different classes of technology and vice versa. For example, one simple matrix might be constructed as depicted in Table 1. The difficulties associated with such approaches are considerable for several reasons. First, there is no general consensus in the literature about the terminology used to categorize and classify errors (Senders & Moray, 1991). Several different taxonomies of human error exist with varying degrees of overlap. For example, studies on “decision errors” may classify errors in terms of “knowledge-based mistakes”, “diagnostic errors” or “planning errors,” although all at some level may be “decision errors.” Furthermore, there is currently no generally agreed-upon framework for classifying different technologies or intervention strategies (Wiegmann & Shappell, 1997). Some researchers have defined them

based on their function (e.g., information processing), while others have defined them based on their modality (e.g., visual vs. auditory displays). Thus, interconnecting human error classes with intervention technologies in a manner that is both meaningful and useful is indeed onerous (Reason, 1990).

Table 1  
*Possible error-intervention matrix.*

Technological Interventions	Displays	Controls	Checklists	Training	...
Error Categories					
Decision					
Skill-Based					
Perceptual					
Communication					
...					

The purpose of the present project is to explore the possibility of developing a comprehensive error-technology matrix for mapping error categories onto technology fixes and vice versa. The project has several phases. The first phase, which is the focus of this report, involved a global review of the repositories of human factors data in order to examine the nature and complexity of data sources, terminologies, and classifications used to relate human error with technology intervention strategies. This information was then used to develop prototypes of data structures or matrices that link errors and technologies in a manner that facilitates the development of standards for evaluating safety products. Follow-on phases of this project will involve a thorough and detailed review of the literature to fill in the data matrix. Application of the matrix to real-world cases will then be attempted to validate the system. We will return to these future efforts after summarizing our progress to date.

## **Part 2: Summary of Phase 1 Efforts**

### ***Error Taxonomies***

In executing this phase of the project, attempts were made to build upon the foundation laid down by the NASA ASAFE program, with regard to the data structures and taxonomies already in place. In particular, the Human Factors Analysis and Classification System (HFACS) has been selected as the error taxonomy, based on its use by NASA and previous reviews of the human-error literature (Wiegmann, Rich, & Shappell, 2000). A description of the error categories contained in this framework will be described in the following sections.

#### ***The Human Factors Analysis and Classification System (HFACS)***

The Human Factors Analysis and Classification System (see Figure 1) is based upon Reason's (1990) model of latent and active failures. It addresses human error at each of four levels of failure: 1) unsafe acts of operators (e.g., aircrew), 2) preconditions for unsafe acts, 3) unsafe supervision, and 4) organizational influences. The HFACS framework was originally developed for the U.S. Navy and Marine Corps as an accident investigation and data analysis

tool. Since its original development, however, HFACS has been employed by other military organizations (e.g., U.S. Army, Air Force, and Canadian Defense Force) as an adjunct to preexisting accident investigation and analysis systems. Other organizations such as the FAA and NASA have explored the use of HFACS as a complement to preexisting systems within civil aviation in an attempt to capitalize on gains realized by the military. These initial attempts, performed both at the University of Illinois and the Civil Aerospace Medical Institute (CAMI) have been highly successful and have shown that HFACS can be reliably used to analyze the underlying human factors causes of both commercial and general aviation accidents (Shappell & Wiegmann, 2001; Wiegmann & Shappell, 2001). Together, these analyses have helped identify general trends in the types of human factors issues and aircrew errors that have contributed to both military and civil aviation accidents.

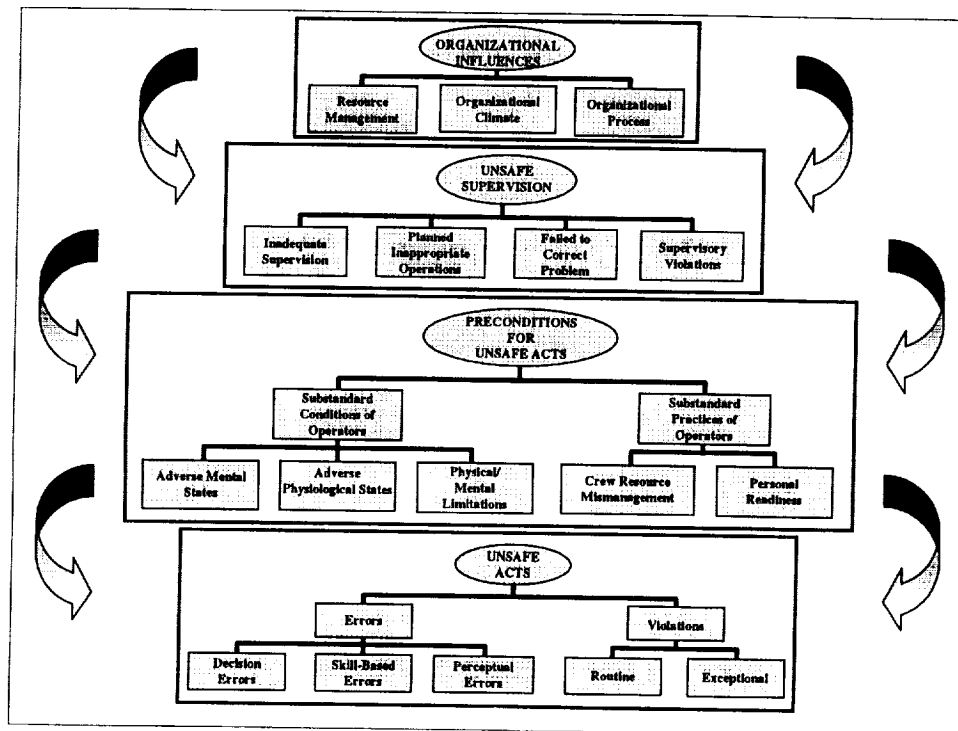


Figure 1. Categories of accident causal-factors within HFACS.

### ***HFACS: Unsafe Acts***

Since the human error or unsafe acts level within the HFACS framework is central to the current research project and program goals, this level of the framework will be described briefly. The following sections will then discuss taxonomies for classifying technologies.

***Defining unsafe acts.*** Within HFACS, the unsafe acts committed by pilots generally take on one of two forms, errors or violations. Errors are generally defined as mental or physical activities that fail to achieve their intended outcome. Violations, on the other hand, represent a willful disregard for rules and regulations. Some examples of aircrew casual factors associated errors and violations can be found in Table 2.

Table 2

*Selected examples of unsafe acts of pilot operators (Note: This is not a complete listing).*

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<u>Errors</u>	<u>Violations</u>
<u>Skill-Based Errors</u>	Failed to adhere to brief
Breakdown in visual scan	Failed to use the radar altimeter
Failed to prioritize attention	Flew an unauthorized approach
Inadvertent use of flight controls	Violated training rules
Omitted step in procedure	Flew an overaggressive maneuver
Omitted checklist item	Failed to properly prepare for the flight
Poor technique	Briefed unauthorized flight
Over-controlled the aircraft	Not current/qualified for the mission
<u>Decision Errors</u>	Intentionally exceeded the limits of the aircraft
Improper procedure	Continued low-altitude flight in VMC
Misdiagnosed emergency	Unauthorized low-altitude canyon running
Wrong response to emergency	
Exceeded ability	
Inappropriate maneuver	
Poor decision	
<u>Perceptual Errors (due to)</u>	
Misjudged distance/altitude/airspeed	
Spatial disorientation	
Visual illusion	

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**Basic error types.** There are essentially three basic error types: skill-based errors, decision errors, and perceptual errors. Skill-based behavior is best described as those “stick-and-rudder” and other basic flight skills that occur without significant conscious thought. Skill-based errors may occur due to individual differences in flying skills or as a result of attention and/or memory failures. Attention failures, for example, produce such skill-based errors as a breakdown in visual scan patterns, task fixation, the inadvertent activation of controls, or the misordering of steps in a procedure. In contrast, memory failures often appear as omitted items in a checklist, place losing, or forgotten intentions. Decision errors represent intentional behavior that proceeds as intended, yet the plan proves inadequate or inappropriate for the situation. They typically represent poor judgment, improper choice of procedure, or the misinterpretation or misuse of relevant information. Finally, perceptual errors occur when sensory input is degraded or “unusual,” and can result in misjudged distances, altitudes, and descent rates, as well as a myriad of visual illusions.

**Violations.** In contrast to the three error forms described previously (decision, skill-based, and perceptual), violations represent a willful departure from those practices deemed necessary to safely conduct operations, and as such are differentiated from errors. Violations are further divided into two types based upon the characteristics of individuals committing them and those who govern their actions. Routine violations tend to be habitual by nature and are typical of the individual’s behavioral repertoire. Equally important, routine violations are often perpetuated by a system of supervision and management that tolerates such departures. Exceptional violations, on the other hand, are isolated departures from authority, neither typical of the individual nor condoned by management.

### ***Classification of Technologies: A Taxonomy of Taxonomies***

A primary focus of this research was to map technologies to human errors (e.g., HFACS categories) and vice versa. Since there are innumerable possible ways of producing human errors in complex systems and equally incalculable number of technologies with which humans interact, both human errors and technologies must be brought together into some kind of classification system to reduce the problem to a manageable size. That is, instead of dealing with unlimited number of causal factors that may contribute to errors as well as innumerable technology solutions, we will have a finite number of error classes to map to a finite number of technology classes. An error taxonomy (i.e., HFACS) has been described in the previous section. Next, we will discuss a similar system for classifying technologies.

To gain a first-hand appreciation of the scope and nature of the problem, a literature search was conducted on new aviation-related technologies and a sample of 100 different technologies was compiled. Descriptions of these technologies appear in Appendix A. The titles of sampled technologies appear in Table 3. As can be seen from this relatively small sample, the number of technologies in the marketplace and under development is bewildering and some kind of a classification system is essential to make the issue approachable. Although there can be almost innumerable possible taxonomic schemes, our goal of mapping technologies to human error effectively limits the number of feasible alternatives. A review of literature also revealed several existing taxonomies that could be applicable to our problem. These will be reviewed first.

#### ***Classification by Application***

The simplest definition of technology is “applied science” (Websters). Application, therefore, appears to be a natural classificatory scheme. An example of such taxonomy is the Defense Technical Information Center (DTIC) Subject Categorization Guide (DTIC, 2000; see Appendix B-1). Other application-based taxonomies are the TII Technology Classification Codes (TII, 2000; see Appendix B-2), the Dewey Decimal System (Forest Press, 2001), and the Library of Congress classification outline for technology (see Appendix B-3).

Particular applications such as displays can be further classified by sensory mode (visual, auditory, and haptic), by type of information (static vs. dynamic, qualitative vs. quantitative, and discrete vs. continuous) (Sanders & McCormick, 1993). A detailed taxonomy of displays based on such schemas was created by Blanchard (1973; see Appendix B-4). Blanchard’s three-level taxonomy was based on the sensory mode at the top level, type of information displayed (e.g., digital readouts, spatial relations) at the next level, and specific technologies used in the displays (e.g., CRT, LED) at the lowest level. This taxonomy does not, however, adequately consider the diversity of applications of the displays or the equally diverse environments in which they might be used. Yet another taxonomy of technologies based on a mix of the particular application and human factors considerations was used by Cardosi and Murphy (1995) in a human factors checklist for design and evaluation of air traffic control systems (see Appendix B-5). This taxonomy does not go into more detail than the top level depicted in the Appendix and is also particular to only the ATC domain.



Table 3

*A sample of 100 aviation/aerospace technologies.*

1. AVOSS aircraft vortex spacing system.
2. Plasma ignition technology.
3. 3-D flight path display.
4. Lightweight split tube insert for tubular brake rods.
5. FMS –vertical profile display.
6. Nuclear powered aircraft.
7. NASA runway incursion prevention system.
8. GWPS coupled with terrain mapping database.
9. Automatic dependent surveillance-broadcast.
10. CFIT simulator training aid.
11. Electronic billing information system.
12. Electromyogram-based flight control system.
13. FSI online training.
14. Cockpit video recorders.
15. Super attenuating ear down.
16. Digital direct-dial satellite communication.
17. Airport, runway construction.
18. Autopilot switches.
19. Helicopter fly-by-wire system.
20. Aircraft cabin guiding lights.
21. Storing pods for military equipment.
22. Inflatable passenger seat restraint system.
23. Collision avoidance system for helicopters.
24. Aircraft crew rest compartments.
25. Six stage turbine engine compressor.
26. Jet fuel additives.
27. Thermoplastics used on aircraft structures.
28. Fire suppression technologies.
29. Maps for airports in hazardous terrain.
30. Computer simulation.
31. CFD design software.
32. E-commerce.
33. Rapid prototyping.
34. Heated floor panels.
35. New anechoic chamber.
36. New wind tunnel blades.
37. Engine trend monitor.
38. Wire harness testing.
39. Terrain awareness and warning system computer.
40. Aircraft coating facility.
41. Airframe noise visualization system.
42. Helicopter paint coating.
43. Low altitude wind shear models.
44. Fighter exhaust systems simulation.
45. Aircraft hydraulic systems modeling.
46. Intelligent tires.
47. Fuel leak detection system.
48. New technology aircraft.
49. New AOA transducer for C-5.
50. New fuel nozzle for AE 3007 turbofan.
51. Direct voice input.
52. Aircraft structural integrity tracking.
53. PC-aided design.
54. New aerospace materials.
55. Biometric handreader.
56. Simulation software.
57. New deicing system.
58. Active noise and vibration control.
59. New propeller blades.
60. New instrument panel lights.
61. Supply chain management solution.
62. Airport management area safety system.
63. Dry-transfer application aircraft markings.
64. Electro-thermal prop deicer.
65. New aircraft window wipes.
66. MX20 multifunction display.
67. Flight situation multifunction display.
68. Lightning warning system.
69. Eight screen glass cockpit.
70. Hydraulic cylinder block manufacturing machine.
71. New borescope technology.
72. Electric constant speed prop.
73. Improved fuselage crashworthiness.
74. Cockpit display of traffic information (CDTI).
75. Flight crew operation software.
76. New radome material.
77. Icarus real-time cockpit instrument display.
78. Diesel engines for GA aircraft.
79. Inflatable aircraft passenger restraints.
80. Infrared aircraft deicing.
81. Integrated circuit time of flight measurement system.
82. Materials for lightning strike protection.
83. Aircraft window shading device.
84. Intake ice protection system for helicopters.
85. Stealth technology.
86. Engine condition health on line software.
87. New A380 avionics and electrical systems.
88. New jet fuel GA engine.
89. Arc fault circuit interrupter.
90. Highway in the sky (HITS).
91. Integrated display/sighting system.
92. Satellite-based airliner e-mail system.
93. Cabin alert and monitoring.
94. New high-speed tire for the Concorde.
95. Flight deck track ball cursor control.
96. Laptop takeoff performance calculator.
97. Infrared ground deicing system.
98. High-bandwidth in-flight internet.
99. Ultrasonic ice detection.
100. Runway debris scanning system.

### ***Classification by Task***

There are numerous taxonomies that consider the particular tasks humans perform with technologies. Because these systems focus from the outset on the human side of the system, they could conceivably provide a common substructure between human performance (i.e., error in particular) and technology. In this scheme, technologies could be classified according to what tasks humans perform with them or what tasks are affected by them.

Task taxonomies reviewed here are further divided into two classes. First, we review those taxonomies which explicitly focus on the tasks, task characteristics, and overt behavior. The second class is formed by taxonomies, which primarily concentrate on the human information processing characteristics and structures, and which only implicitly use this scheme to classify tasks. This distinction is somewhat arbitrary, but we will demonstrate its usefulness later in the report.

Of the task-descriptive taxonomies, the first example is the Willis input-output hierarchical model (Willis, 1961; see Appendix B-6). This model's topmost classification scheme is based on a generic human information processing model, but the subclasses describe actions relevant to the task. Berliner, Angell, and Shearer (1964; see Appendix B-7) classified tasks according to human information processing characteristics (e.g., perception, problem-solving, and decision-making) and descriptive verbs (e.g., detects, inspects, interpolates, etc.) as well. Fitts' taxonomy (Fitts, 1965; see Appendix B-8) classified tasks according to the elements required for task performance. This simple taxonomy has only one level and it omits stimuli characteristics as a classificatory structure, limiting its usefulness for our purposes. Meister's detailed taxonomy, on the other hand, contains extensive and detailed classification of the stimuli, but is short on task-related actions (Finley, Obermayer, Bertone, Meister, & Muckler, 1970; see Appendix B-9). Farina and Wheaton (1971; see Appendix B-10) classified tasks according to their characteristics, such as goals, responses, and procedures, but also included stimulus characteristics and stimulus-response relationships in their taxonomy. Finally, Shingledecker, Crabtree, and Acton (1982) used the information processing framework as the top level scheme and task requirements at lower levels (see Appendix B-11).

An example of domain-specific task taxonomies is Carter's (1986; see Appendix B-12) taxonomy of user-oriented functions. This taxonomy of human-computer interactions is very detailed, and although its focus is too narrow to make it useful for our problem, it nevertheless serves as an exemplar of level of detail necessary for certain specific applications

### ***Classification by Human Information Processing System***

It is difficult to exactly determine the division between task taxonomies described in the previous section and taxonomies of human information processing. The two necessarily have substantial overlap. The human information processing framework forms a basis for most task taxonomies reviewed. However, as we are looking for candidate systems for mapping technologies to errors, all taxonomies concentrating on human performance deserve a detailed look.

The human information processing framework is based on a number of similar models proposed by different investigators (e.g., Broadbent, 1958; Smith, 1968; Sternberg, 1969; Welford, 1976) and the form of the framework presented in Figure 2 is a composite of these (Wickens, 1984). The framework depicts human information processing in the form of sequential stages. Stimuli must be sensed in the first stage and perceived in the second. The third stage involves higher cognitive processes, such as decision-making, problem-solving, and

response selection, and the fourth stage action execution. There are three other components in the model that interact with these stages: attentional resources, and working- and long-term memory. Finally, a feedback loop completes the system.

A human information processing taxonomy based on this framework is presented in Appendix B-13. This taxonomy is not complete, but its level of detail makes it easy to see how it could be expanded. There are a myriad of other taxonomies that follow this framework to a varying degree, primarily depending on their original purpose. Miller's (1962; see Appendix B-14) system described behaviors associated with task performance (Gawron, Drury, Czaja, & Wilkins, 1989). It is noteworthy that not all Miller's tasks were overt, but also covert behaviors were included, such as retention of task information. Parallelism between Miller's taxonomy and the human information processing framework is easy to see. Meyer, Laveson, Pape, and Edwards (1978; see Appendix B-15) used verbs as a subcategory scheme under a coarse dichotomy of mental and motor actions. Gagne's (1974) taxonomy of central nervous system processes provides a detailed classification of problem solving (see Appendix B-16). A detailed taxonomy of what is essentially the response execution stage was constructed by Harrow (1972; see Appendix B-17). This taxonomy of the psychomotor domain distinguishes between reflex movements, perceptual abilities, physical abilities, and skilled movements and could be used in part to augment the information processing taxonomy. Hindmarch's (1980) taxonomy was constructed for classification of the effects of psychoactive drugs, but it, too, follows the information processing framework while offering an alternative to Harrow for motor control subclass structure (see Appendix B-18). Finally, Parasuraman, Sheridan, and Wickens' (2000) classification of human interaction with automation faithfully replicates the four stages from the information processing framework, showing how it can be used as a classificatory scheme for automation (see Appendix B-19).

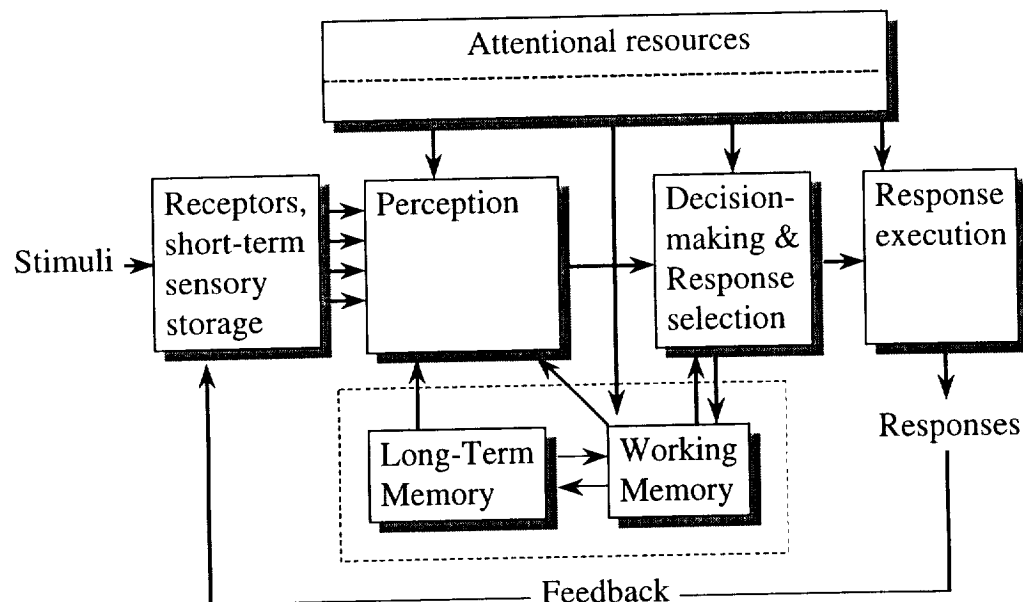


Figure 2. The human information processing framework.

### ***Theory-Based Classificatory Schemes***

In addition to the information processing framework, numerous other theories and models of human performance exist and each can serve as a foundation for a taxonomy of human performance. One influential model is information theory (Shannon & Weaver, 1949). A task classification system based on this theory was proposed by Levine and Teichner (1971; see Appendix B-20). This taxonomy classifies tasks according to their constraints, level of redundancy, and input-output relation. The utility of information theory in human factors research is undisputed and predominantly due allowing information to be quantified in an unambiguous manner. However, like all theories and model, information theory has its limitations and the applicability of Levine and Teichner's taxonomy to our problem is not clear.

### ***Environmental Taxonomies***

A special subclass of the human factors taxonomies reviewed here are taxonomies of environmental factors. Human performance never occurs in isolation and therefore a taxonomy of human factors cannot be complete without attention to the environment. Chambers' (1969, see Appendix B-21) provides a detailed and comprehensive example of the environmental variables of consideration.

### ***Comprehensive Human Performance Taxonomies***

As can be seen in the review above, many of the taxonomies sampled are very limited in scope and often lack sufficient detail even in their own narrow domains. Several attempts to create a comprehensive human factors taxonomy have been made. Chambers (1969) reviewed existing human performance taxonomies and developed a heuristic model to aid in further classification efforts. The model itself serves as a useful taxonomy by making a broad distinction between the independent, intervening, mediating, and dependent variables affecting human performance (see Appendix B-22).

Another ambitious taxonomy of human performance was developed by Gawron, Drury, Czaja, and Wilkins (1989). This taxonomy was generated from a review of existing human performance taxonomies by including in it independent variables affecting human performance (cf., Chambers, 1969) and streamlining the definitions of the variables to eliminate duplicity and ambiguity. This extensive taxonomy is presented in Appendix B-23.

Finally, the American Institute for Aeronautics and Astronautics (AIAA) launched, in the late 1980's, an extensive effort to create comprehensive human factors taxonomy for an American National Standard. This work was never published, but a draft taxonomy is presented in Appendix B-24. This presentation is limited to the top four levels; the original work included 11 levels.

### ***Interim Summary: Evaluation of the Existing Taxonomies***

The above review is by no means comprehensive, as it can be safely concluded that there exists as many taxonomies as there are purposes, and many widely used taxonomies are not necessarily published. This review, however, allowed for a general overview of the classification science and the many attempts to bring the diverse of human-machine interactions within a manageable framework (Table 4). The review also revealed several shortcomings of the general taxonomic approach, as far as our objectives are concerned.

Table 4

*A taxonomy of taxonomies pertaining to human-machine systems.*

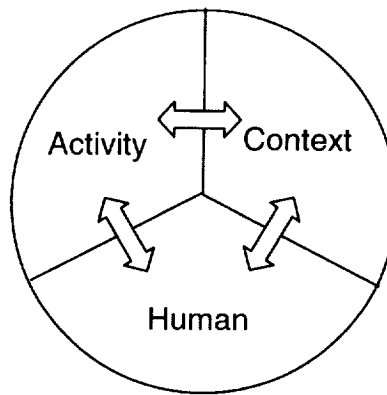
- 
1. Classification by Application
    - DTIC (2000)
    - TII (2000)
    - Dewey Decimal System (Forest Press, 2001)
    - Library of Congress
    - Blanchard (1973)
    - Cardosi and Murphy (1995)
  2. Classification by Task
    - Willis (1961)
    - Berliner, Angell, and Shearer (1964)
    - Fitts (1965)
    - Finley, Obermayer, Bertone, Meister, and Muckler (1970)
    - Wheaton (1973)
    - Shingledecker, Crabtree, and Acton (1982)
    - Carter (1986)
  3. Classification by Human Information Processing System
    - Wickens, (1984)
    - Miller (1962)
    - Meyer, Laveson, Pape, and Edwards (1978)
    - Gagne (1974)
    - Harrow (1972)
    - Hindmarch (1980)
    - Parasuraman, Sheridan, and Wickens (2000)
  4. Theory-Based Classificatory Schemes
    - Levine and Teichner (1971)
  5. Environmental Taxonomies
    - Chambers (1969)
  6. Comprehensive Human Performance Taxonomies
    - Chambers (1969)
    - Gawron, Drury, Czaja, and Wilkins (1989)
    - American Institute for Aeronautics and Astronautics (AIAA)
- 

There are several criteria for evaluating taxonomies. These include the ease of use (for the intended purpose), completeness, accuracy, and reliability (Chambers, 1969). For this research the obvious test would be to attempt to classify the 100 sampled technologies according to each reviewed taxonomy. This would not be possible, however, for obvious reasons. The level of detail available for each technology in our sample was not nearly sufficient to allow even their coarse classification. Furthermore, it is clear that none of the taxonomies reviewed could accommodate the technologies and their manifold effects on humans. Two conclusions can be made that will be crucial for further development of a framework accommodating both human error and technologies: First, a thorough task analysis is necessary for each technology and its specific application to facilitate their subsequent classification with sufficient accuracy. Second, due to the multidimensional nature of human-machine interaction, no one- or two-dimensional taxonomy can offer a robust and unambiguous framework for their classification. These conclusions are discussed further in the next section.

### ***A Systems Approach***

As human error is central to our approach, and human error can be understood as synonymous to human performance (i.e., poor performance or failure to perform), a human performance model is a necessary starting point for the framework mapping errors and technologies. Human performance, however, seldom happens in isolation, but is affected by a myriad of factors. These factors must necessarily be considered in the framework. Also, to successfully map human errors to various technologies and vice versa, it is obvious that a set of commonalities between each must be identified. An element common to both humans and technologies is the task. Humans use technology as tools to accomplish certain tasks, or technologies may require humans to perform tasks on them (e.g., maintenance). Hence, a system approach is deemed as the only reasonable and useful way of linking human errors with technologies. In essence, the human and the machine form a system (Rouse, 1980). According to this definition, “machine” is other than human (i.e., technology), and the human-machine interaction can be depicted in an input-output diagram, where the human’s outputs are the machine’s inputs and the machine’s outputs are the human’s inputs (Rouse, 1980).

There are several qualitative models of human performance that are generalizable to all performance situations and that can serve as a foundation for a framework of a human error-technology taxonomy. The SHEL model (Edwards, 1988) described a system consisting of four elements: Software, Hardware, Environment, and Liveware (i.e., the human). Several human performance models use this conception as well. Bailey (1982) proposed a general, qualitative, model of human performance that is generalizable to all performance situations (Figure 3).



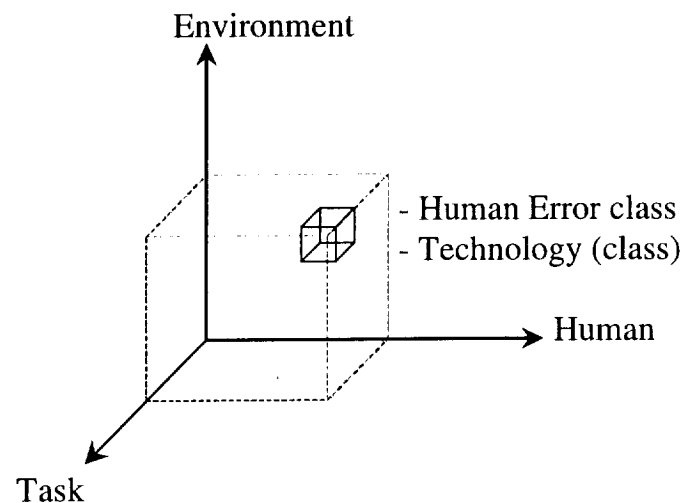
*Figure 3.* Bailey’s (1982) qualitative model of human performance.

### ***A Three-Dimensional Framework***

It is clear that the models must contain at least three critical elements: the human operator, his or her task, and the environment or context in which the task is performed. There are also several task taxonomies that entail all or parts of these elements, for example Gawron, Drury, Czaja, and Wilkins’ (1989) human’s taxonomy, which had three major branches: environment, subject, and task. Although the majority of these factors remain unknown at worst and poorly understood at best, and although the number of variables and their potential interactions can be

bewildering, the systems approach we have adopted offers some startling benefits in linking such disparate realms as human performance and technological innovations.

Given the multidimensional nature of the problem, the framework adopted for this proposition is three-dimensional. It will consist of three axes, one for the human operator, one for the task, and one for the environment. There are several existing, published taxonomies for each axis, too. Because human errors can be mapped to all of these dimensions, albeit not uniquely, the fourth dimension of the problem can thus be placed within the “molecules” (i.e., three-dimensional cells) in the matrix. Furthermore, technologies can be mapped to tasks and environments as well as to human characteristics (e.g., *visual* displays, *auditory* alarms) and placed within the aforementioned framework. Hence, human errors and technologies will co-habit molecules in the matrix, linking them together (Figure 4).



*Figure 4.* The proposed three-dimensional matrix for mapping human errors and technological innovations.

### ***Example : Head-Up Displays for Airliner Cockpits***

To illustrate the framework developed here, we chose a particular technology for closer examination. The Head-Up Display (HUD) represents a recent technological innovation with significant safety implications but also some surprising drawbacks. Furthermore, there exists a considerable body of research relevant to the technology and its applications.

### ***Classification Issues***

The first issue is the proper classification of the HUD technology in the framework. Given the proposed three-dimensional framework, the HUD should be classified along all three axes. Although no complete taxonomies have been defined for the environmental-, human-, and task dimensions of our framework, certain taxonomies reviewed earlier offer viable starting points. For the environment-axis, Chamber’s (1969; see Appendix B-21) taxonomy provides for a useful template. Considering HUD technology for airliner flight deck applications, it should be

classified according to the environmental categories present in this environment. Hence, HUD relates to nearly all of the elements in Chamber's taxonomy. Of the physical environmental categories, pressure, thermal, acceleration, and vibration will certainly affect pilots' performance in using the HUD. Other categories relevant to HUDs and to be added in the physical environment taxonomy might include lighting. On the social environment side, categories such as "crew-2-person" and "professional" are viable class candidates for the taxonomy.

On the "Human" axis, HUD technology should be classified to the following categories (see Appendix B-13): Vision (including all subcategories), perception-attention-divided attention, long-term memory-event memory-episodic memory, long-term memory-semantic memory-declarative and procedural memory, and working memory-cue reception and integration. Finally, along the "task" axis, HUD technology could be classified according to the Berliner scheme (see Appendix B-7) by perceptual, mediational, and problem-solving and decision-making processes and all of their subcategories.

### ***Human Error Links***

The close spatial proximity, or closeness in space, of information presented in a HUD should enable parallel processing (Wickens & Hollands, 2000). Such parallel processing can often facilitate divided attention and reduce demands on short-term memory, thereby reducing attentional slips and memory lapses that cause skill-based errors. Both perceptual errors and decision errors might also be reduced by the presentation of unambiguous information in an integrated display. Still, according to the 3D error-technology matrix, other factors also need be considered that could mediate these potential benefits. For example, vibration experienced in cockpits could deter from the interpretation of various symbologies used in the display. In addition, tasks that require the separation of information (focused attention) during flight might be hindered by the simultaneous overlay of data in a HUD, producing potential errors in perception and decision-making. Further development of the 3D matrix in which these links are known will obviously facilitate such analyses by helping one pinpoint the most prominent sources of human error associated with a particular technology, as well as its applications for specific tasks in various operational environments. Exhaustive review of research literature is essential for the establishment of such links.

### ***Additional Issues: Task Analysis***

It should be already evident from the discussion above that proper classification of technologies is not a trivial matter for two reasons. This task is of critical importance to the outputs of our proposed framework, that is, accurate and comprehensive linking of technologies with human error, but it can be successfully completed only by conducting thorough task analysis of every technology in every application and in every environment and by all potential users. Unfortunately, there exists very few published task analyses, even for existing technologies. Although this lack of obligatory data for our framework can be seen as a drawback of the approach we adopted, it is clear that detailed scrutiny of the entries in the framework (i.e., technologies) is imperative if any useful information is to be gained. Consequently, a broad, general approach in the domain of human-machine interaction where innumerable variables and their interactions exist simply will not be justifiable. Hence, the progress that is achievable in further development of the framework and its usability are inextricably linked to the availability of task analyses associated with various technologies. On the other hand, it is conceivable that the proposed framework will become a useful and usable database that effectively reduces parallel and overlapping research efforts.



## **Summary**

Initially, we have used combinations of existing human, task, and environmental taxonomies for the three axes of the matrix. These taxonomies must remain dynamic, however, with new classes, subclasses, and sub-subclasses added or deleted according to the known technologies, their applications, and human error types that are entered into the framework. Hence, our approach will also serve as a vehicle for taxonomic development in all three areas pertaining to human performance and its validation will be a continuous process in lieu of a one-time effort. This framework will also direct further work deemed essential for the comprehensive solution to the problem. These efforts will be described next.

### **Part 3: Outline of Phase 2 Efforts**

The scope of the task of providing a comprehensive mapping between technologies and human error is only beginning to emerge after the first year's efforts. However, we strongly feel that careful attention to the creation of a robust conceptual framework is essential for the success of future research, which must proceed in a deliberate and systematic manner as well. The next steps in this effort are outlined here in terms of what can reasonably be accomplished in another year's time. Two main thrusts in this work can be identified. First, to build upon the conceptual framework presented in this report, the literature search must be extended to selected domains and all available research reviewed. Second, the framework must be "filled" with case studies, which will serve as evaluation tools as well as set an example for the complete structure.

### ***Literature Review***

#### ***Task Analyses***

Task analysis is an essential component of our model. Unless a thorough task analysis is conducted for each example of technology, we will not know who are the users, how the user(s) will use the technology, and how the users' performance will be affected by the technology. The method used to answer these questions is task analysis. Several techniques for task analysis exist and task analysis is an essential part of any system development. The literature search in Phase 2 will therefore concentrate on task analyses that have been performed by the developers of the technologies in question. This aspect might present a problem, however, as data and specifications pertaining to new technologies is often proprietary by nature and therefore jealously guarded by the company. The criticality of this information is nevertheless indisputable.

#### ***Empirical Research***

The proposed framework will allow for a directed literature search and review of both empirical and theoretical research that will help in establishing the direction of the impact of a given technology and its application on human error (i.e., a cause of an error or a remedy for an error) as well as the particular mechanisms of such relationships. We anticipate, however, that our framework will consist of mostly "empty space," that is, that there will be several uncharted areas of human interaction with technologies. Hence, year-two efforts will serve an important role in identifying areas where research is lacking and where sufficient data in the literature may not be available for informed decisions about fielding new technologies, for example.

### ***Focused Case Studies***

Another method of filling the framework is to use case studies. In Phase 2, we will seek to collaborate with engineers from Volpe Center and other NASA supported laboratories. A small number of case studies which will benefit from the availability of task analyses and empirical data of human-machine interaction will aid in further developing the framework, refining the taxonomies along the three axes, as well as refining the definitions of both errors and technologies inhabiting them.

### ***Database Development***

To make the proposed framework usable, it must be brought into a database format which is flexible, expandable, fully accessible by a multitude of researchers and users, and which can be continually developed as new information becomes available. Given the magnitude of the project, as well as its potential value to the worldwide human factors community, a distributed development environment must be considered indispensable. The development of such a database, however, is contingent on the successful completion of the previous tasks and will require the utilization of experts in information science and engineering.

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## **Appendix A.**

### **A Sample of Technologies.**

#### **1. AVOSS Aircraft Vortex Spacing System.**

Developed by NASA Langley Research, the AVOSS Aircraft Vortex Spacing System is designed to prevent aircraft wake turbulence on final approach by spacing airlines more safely. AVOSS predicts effects on wind and other atmospheric conditions on wake vortex patterns of different aircraft types using a laser radar (LIDAR) technology to confirm these forecasts to air traffic controllers and pilots. AVOSS is in test phase at DFW demonstrating a 15% increase in runway capacity depending upon weather conditions and number of heavy aircraft arriving. [Hinton, D. (2001, January/February). NASA seeks to ease congestion. *Aerospace Engineering*, p. 11.]

#### **2. Plasma Ignition Technology.**

Plasma ignition technology developed by Unison Industries can initiate and stabilize combustion of solids, liquids, and gaseous fuels that previously could not be ignited by energy spark systems. The technology enables more sophisticated and cost efficient combustion systems to be used and reduces pollutants. It is used on current ground-based turbine engine systems with later application on aircraft. [Bokulich, F. (2001, May). Plasma ignition technology. *Aerospace Engineering*, p. 11.]

#### **3. 3-D Flight Path Display.**

Currently, pilots assimilate large amounts of text data to construct a 3-D image of current and anticipated aircraft situation. Rockwell Collins believes 3-D flight path display will depict the flight plan and predicated vertical aircraft trajectory on multifunctional display (MFD) to provide a desirable alternative and more efficient means for pilots to understand the FMS system. Combination of FMS, FMC and CDU technologies provide pilots with a 3-D flight path display presentation, which depict graphically the flight plan and predicted vertical trajectory on a multifunctional display (MFD). [Owen, G. (2001). 3-D flight path display. *Aerospace Engineering*, 21(3), pp. 17-20.]

#### **4. Lightweight Split Tube Insert for Tubular Brake Rods.**

BF Goodrich Aerospace has developed a method to dampen the bending mode of the brake rod to landing gear structure to reduce vibration and squeal. New technology reduces pitch-plane torsion oscillation of the non-rotating brake structure by dampening the bending mode by using a lightweight split tube insert for tubular brake rods. New split sleeve design and material technologies can be integrated into current aircraft operations therefore reducing irritant vibration and noise pollutants found in aircraft cabins. [Enright, J. (2001). Reducing brake squeal. *Aerospace Engineering*, 21(3), pp. 5-27.]

#### **5. FMS –Vertical Profile Display.**

Simple profile view of the flight management system (FMS) vertical flight path can be provided using current cathode ray tube (CRT) electronic horizontal situation indicator (EHSI) with a software program in FMS when in the map mode. 3-D graphical representation of FMS

vertical profile can be provided by a multi purpose high-resolution flat panel display through the integration with the Terrain Awareness and Warning System (TAWS). Enhanced configuration is preferred that integrates both 3-D and horizontal views with high-resolution terrain on primary flight displays. [DeJonge, M., (2001, April). FMS-vertical profile. *Aerospace Engineering*, pp. 31-34.]

#### **6. Nuclear Powered Aircraft.**

Nuclear power is proposed as a possible replacement for current transport propulsion technology for efficiency and cleanliness of thermodynamic process. Using nuclear power in a closed-cycle steam engine driving propellers would reduce aircraft weight, engine emissions and reliance upon fossil fuels. [Poll, I. (2001). Nuclear powered aircraft. *Aerospace Engineering*, 21(4), p. 5.]

#### **7. NASA Runway Incursion Prevention System (RIPS).**

NASA runway incursion prevention system (RIPS) technology was developed to provide pilots with alerting mechanism to warn of possible runway incursions. Equipment includes Rockwell Collins GNLU-930 multi mode receiver, GPS, Automatic Surveillance Broadcast (ADS-B) equipment. The system has been demonstrated at DFW using several scenarios between aircraft and van. GPS system demonstrations were augmented by differential GPS correction to provide highly accurate data. [Bokulick, F. (2000, December). Improving safety and awareness. *Aerospace Engineering*, p. 11.]

#### **8. GWPS Coupled With Terrain Mapping Database.**

Terrain data was integrated with GWPS system to present pilots' aircraft position information in cockpit displays. [Dornheim, M. (1996, November). New technology, target training CFIT losses. *Aviation Week and Space Technology*, pp. 73-77.]

#### **9. Automatic Dependent Surveillance-Broadcast.**

ADS-B provides IFR aircraft separation in non-radar areas of southwest Alaska is step toward modernization of ATC system. ADS-B will be able to fill gaps between highly developed and under developed countries giving ATC controllers a means to track and separate aircraft at low altitudes and in regions that lack radar coverage. ADS-B equipped aircraft continuously broadcasts digital data link signals of its GPS position. ADS-B aircraft symbol appears on controller displays, giving a radar track. Pilot situational awareness is also improved as they can see locations of transmitting aircraft on cockpit displays. [Nordwall, B. (2001, January). ADS-B used for IFR vectors. *Aviation Week and Space Technology*, p. 48.]

#### **10. CFIT Simulator Training Aid.**

Flight Safety Foundation's CFIT task force is working with Boeing to develop a simulator based training aid for pilots, aimed at preventing CFIT accidents. Common misconception of CFIT accidents involves crews getting lost and flying into terrain. Data shows, however, that CFIT accidents usually occur on final approach with aircraft lined up with runway at normal rate of decent, making it a vertical position error problem. The training aid consists of comprehensive training manual, sample simulator program, and 25 minute video and it is designed for major-, regional- and commuter airlines. [Hughes, D. (1995, July 10). CFIT task force to develop simulator training aid. *Aviation Week and Space Technology*, p. 34.]

### ***11. Electronic Billing Information System.***

A new PC based electronic billing information system is designed to increase company efficiency, productivity and profitability for aircraft maintenance businesses and technicians. This new computer program billing system is designed to track all aspects of an aircraft maintenance business including but not limited to work orders, labor hours by employee, parts inventory, and billing. The program directly integrates both office and shop-floor environment for estimates of real time performance against estimates. [Gauntt, T. (2001, March). Need help with paperwork? *Aviation Maintenance*, p. 47.]

### ***12. Electromyogram-Based Flight Control System.***

NASA Ames Research Center landed a 757 at San Francisco International Airport using pilot muscle nerve signals transmitted through a pilots forearm. The arm band married to an electromyogram with software developed by Ames that allowed hand and arm movements to control the aircraft as if grasping the joy stick. Two tests were conducted. First, was a simulated landing approach to SFO using electromyograms, and the second concerned emergency procedures using and combine muscle nerve studies. When combined the neuroelectrically wired pilot flew several landing scenarios with cascading failures (locked rudder controls to full hydraulic failure. Similarly, a controlled landing in another test was through virtual typing. Other applications successes consist of controlling aircraft in various emergency situations. All landings were successfully completed. [Mecham, M. (2001, March 5). Ames researchers "land" 757 with nothing but muscle. *Aviation Week and Space Technology*, p. 51.]

### ***13. FSI Online Training.***

New aircraft systems online training program provides maintenance technician students with a distance learning approach to system troubleshooting training. Flight Safety International has launched an online learning program for technicians that teach troubleshooting principles in a two per day format. Individuals can log in from anywhere in the world where the class is done in real time with a live instructor. Training consisted of classroom presentation, computer simulations and testing. Split screen format provided the student with learning material right screen and communications on the left. [Thurber, M. (2001, March). Online training. *Aviation Maintenance*, pp. 38-39.]

### ***14. Cockpit Video Recorders.***

Cockpit video recorders (CVDRs) are expected to be of considerable use for accident investigation and safety training in the glass cockpit environment. Accident investigators are interested in the comparison of match between the pilots' instrumentation/presentation and that of the flight data recorder. Off the shelf camera technology introduced into the cockpit environment using a dedicated microcomputer's external 5x2 inch diameter camera is sealed with nitrogen and has a heated conformal window. Camera technology application will aid investigators in looking at fast-paced crew non-verbal communication channels not currently recorded. [Dornheim, M. (1996, November 4). Video recorders may be in service soon. *Aviation Week and Space Technology*, p. 77.]



### **15. Super Attenuating Ear Down.**

Dalloz Safety has introduced Bilsom 202NST disposal earplugs with super attenuating EarDown foam material for pilot and ground crew personnel. The new ear plugs features uniform and moderate attenuation so wearer can hear voices, warning signals, and other sounds. Constructed of polyethylene film containing no additives and are color-coded. Earplugs are designed to increase comfort and uniform attenuation in all types of environments. [Benoff, D. (2001, March). Super attenuating EarDown. *Business & Commercial Aviation*, p. 104.]

### **16. Digital Direct-Dial Satellite Communication.**

Pilot and passenger controlled direct-dial satellite communication are designed to enable people to use their favorite wireless device from land/air/sea environments to reach anyone in the world. Progress is being made in developing a cabin oriented satellite communication system. This new communication system, requires several links in the communication chain. To make contact with people or data services from the air, ground station "gateways" provides message links to satellites thereby communication with aircraft. Aircraft are being equipped with servers or devices to establish onboard local area networks. There are six in-development and/or proposed major communication/IFE ventures. Basic direct broadcast satellite systems are currently STC'ed and are available for Bombardier Challenger 604 aircraft. [Tripp, E. (2001, March). All things digital. *Business & Commercial Aviation*, pp. 78-85.]

### **17. Airport, Runway Construction.**

A recent Air Traffic Control Association seminar revealed widespread agreement in the aviation ATC controller community that construction of new airports and runways is the only way to reduce traffic operations congestion. "Procedural changes will result in 3-4 operations per hour at most airports" said Steve Brown, FAA Associate Administrator for ATC Services. While a new runway could add 30 to 40 operations per hour, GAMA's president Ed Bolin said "Tweaking the ATC would produce a 15% in system capacity." However, there was also agreement that airport congestion be reduced by the addition of new concrete runways. More available runways provide additional flight path resources reducing congestion. [Collogan, D., (2001, March). More airports, runways seen as congestion fix. *Business & Commercial Aviation*, p. 26.]

### **18. Autopilot Switches.**

Concern over inadvertent autopilot engagement or mode changes during critical phases of flight has led the FAA to look at "protecting" or relocating autopilot switches now installed on control wheels of turbine aircraft. FAA is considering certification guidelines changes for all turbine engine aircraft in the normal, utility, acrobatic, and commuter categories. A suggested fix would be installing a protective switch cover to eliminate unwanted flight crew mode changes during flight such as control wheel steering functions (CWF). CWF is a button that allows the pilot to interrupt the autopilot momentarily and hand-fly the aircraft. Typical cover must be lifted prior to engaging CWS. A second option is to relocate switch from the control wheel to a panel location. Changing switch location and activation procedures would require a modification of pilot habits and training procedures. [Marshall, B. (2001, March). Autopilot switches under FAA scrutiny. *Business & Commercial Aviation*, p. 19.]

### ***19. Helicopter Fly-By-Wire System.***

The Institute of Aerospace Research at the National Research Council of Canada performed its first fly-by-wire (FBW) engagement of a Bell 412 advanced systems research aircraft. The pilot operated the helicopter using a single side stick controller. The test included several single and four axis engagements. Typical fixed wing side stick controller applied to a helicopter application in 4 axis motion creates the ability to modify dynamic characteristics of baseline airplane/helicopter. The airframe then becomes an airborne simulator fully capable of real time evaluation of specific dynamic issues such as optimal control sensitivity, control system band width. Aircraft can be programmed to represent entire future airframe concepts that can be evaluated in flight well before final design is completed. [Bokulich, F. (2001, June). Bell 412 fly-by-wire system flown. *Aerospace Engineering*, p. 14.]

### ***20. Aircraft Cabin Guiding Lights.***

Floor lighting for airline passenger evacuation during emergencies in low or zero light conditions has been developed. This new product replaces conventional electrically lit floor path emergency lighting and requires only occasional cleaning. This new technology increases cabin safety, reduces aircraft weight, eliminates an airframe electrical system, reduced maintenance requirements. [Birch, S. (2001, April). Guiding lights. *Aerospace Engineering*, p. 4.]

### ***21. Storing Pods for Military Equipment.***

Transportation and long-term storage of military equipment calls for increasingly specialized systems with particular focus on relative humidity control. Storage may be for up to five years and container will have a 20-year service life. It must protect against extreme environments and handle shock and vibration loads. This new container structure uses steel wire shock and vibration-isolation mounts to limit pod acceleration to less than 6g when subjected to free fall drops, horizontal impacts and random vibration. Internal relative humidity is controlled to less than 50% by a silica gel desiccant charge. This can be replaced without removing the lid. Each container weighs 2000kg and stackable three high. [Birch, S. (2001, April). Storing pods from EPS logistics. *Aerospace Engineering*, p. 10.]

### ***22. Inflatable Passenger Seat Restraint System.***

Amsafe's inflatable passenger seat restraint system has completed certification testing. With certification granted the system will enter the airline industry. Patented system was based on mature automotive supplement restraint technology, which has been adapted to aircraft requirements. The system uses an electronic detection system to detect impending impact; after diagnosing the event, it deploys an air bag cushion. The air bag cushion is stored in the fixed portion of the passenger lap belt and upon activation it deploys away from the passenger and shields head and upper torso from severe trauma from bulkhead or other structures. Application of current automotive seat restraint technology will dramatically reduce injuries and deaths in aircraft incident and accidents. [Bokulich, F. (2001, April). Amsafe's inflatable restraint enter service. *Aerospace Engineering*, p. 12.]

### ***23. Collision Avoidance System for Helicopters.***

BF Goodrich Avionics Systems has developed the Skywatch traffic avoidance system for rotary wing aircraft. The company received STC for Bell 206B jet Ranger. Skywatch has been

used to enhance situational awareness of military, offshore oil, and general aviation pilot. The system operates as an air-to-air, air-to-ground interrogation device. System computes responding aircraft range, bearing, relative attitude, closure rate predicting potential traffic alerts. Aural alerts are annunciated using existing aircraft audio system and visual targets displayed using TCAS symbology. The system is capable of tracking 30 intruding aircraft simultaneously, displaying eight most threatening. Interface capabilities include ability to share 3 inch ATI CRT display with the Stormscope WX-1000 weather mapping system. [Bokulich, F. (2001, April). Collision avoidance for helicopters. *Aerospace Engineering*, p. 16.]

#### **24. Aircraft Crew Rest Compartments.**

B/E received patent for its overhead flight-crew rest compartments used on Boeing 777 aircraft. The compartments house eight sleeping bunks and two seats for crew use on long-haul flights. The compartments are located in an unused overhead area in the 777 freeing up valuable cargo space by replacing existing rest areas. The new technology rest facilities weigh half as much as the ones they replace. The location and design criteria minimize the impact to the main cabin and maximize customer operations allowing airlines to have a common crew rest on both existing and new aircraft. The design also adapts to customers configuration needs and uses existing vestibule location. Optional vestibule and bunk/seating configurations are also available. [Bokulich, F. (2001, June). B/E aerospace crew rest compartments. *Aerospace Engineering*, p. 14.]

#### **25. Six Stage Turbine Engine Compressor.**

Munich based MTU Aero engines is developing a new HPC12 experimental turbine engine compressor. The compressor section consists of a six stage transonic high-pressure compressor with a pressure rise capability of 11:1 and is designed as a fully functional unit. The compressor is to be installed on the Eurofighter instrumented production aircraft. The powerplants future application would be for large business jets and regional jets. The powerplant is designed to offer enhanced economics, lower noise 30db(A) levels, and emissions. The new manufacturing program is aimed to reduce costs by 30% with lower life cycle costs. Powerplant output is likely to be at the 10,000 lb thrust for the 50-60 seat aircraft and 18,000 lb thrust level for the 100 passenger version. The new concept integrates a reduction gear between the fan and low-pressure turbine. Current production engines use a straight shaft for coupling. The design proves that an engine with high speed/low pressure turbine transmits its power to the fan via gear box will distinctly improve consumption, noise, and costs. [Birch, S. (2001, March). Six stage compressor program. *Aerospace Engineering*, p. 8.]

#### **26. Jet Fuel Additives.**

Dutch Airline KLM is the first commercial operator to trial a jet fuel additive originally developed by BetzDearborn for the USAF. It is aimed at providing environment and economic benefits. The additive is being used on two 747-400 aircraft powered by GE CF6-80 engines. The high temperature dispersant/detergent chemistry performs a similar function to that featured in automotive and diesel fuel additives. Trial expectation hope to prove similar benefits in aircraft turbine engines equal to that of the automotive application. The new additive is designed to keep fuel systems and fuel injectors clean, reduce exhaust emissions, improve fuel efficiency, lower maintenance costs. The additive used in this test was developed as a part of a USAF research and development program to develop a fuel with enhanced thermal stability reducing

the tendencies to degrade and form carbon deposits, lacquers, and coke in combustion chamber areas. Engine performance efficiency increases are achieved by keeping spray nozzles clean, therefore, more efficient combustion process can take place and reducing thermal stress. [Birch, S. (2001, March). Fuel additives first for KLM's Boeings. *Aerospace Engineering*, p. 11.]

#### **27. Thermoplastics Used On Aircraft Structures.**

Fokker Special Products has adopted a Fortron polyphenylene sulfide (PPS) material glass fabric composite material for the inboard leading edge nose on A340-500 and 600 series aircraft. The composite, trade named Cetex, is a continuous-reinforced thermoplastic. The PPS composite replaces the aluminum used in the application to reduce weight by 20%. Prior to the use of the composite material for this application, Airbus used a five section aluminum "D-nose" design for the inboard leading edge section that sits forward of the front spar main wing spar box. The new composite nose section uses a "J-nose" design that forms the leading edge between the fuselage and engine nacelle. Enclosed in the composite section is an electric wiring, deicing and other airframe systems. The new J-nose section component is reinforced by arched shaped ribs and stiffeners. It is rigid across the cross section but flexes along wing length. The new composite material is quick to fabricate, improved impact resistance, high temperature tolerances from -55 to 80 degrees C, good resistance to hydraulic fluids, deicing agents, fuel and other chemically aggressive fluids. Product material consists of glass fabric combined with a film of PPS "semi-preg" for skin manufacturing. Pre-consolidated sheets have five layers for compression molding ribs and stiffeners. Special sizing compounds applied to glass helps material bond to PPS-glass. It is then cured in autoclave at over 300 degrees C and elevated pressures. The components are then pressed, formed, machined to shape, and resistance welded to create strong cohesive unit. [Bokulich, F. (2001, March). Thermoplastics used on Airbus aircraft. *Aerospace Engineering*, p. 10.]

#### **28. Fire Suppression Technologies.**

Hughes Associates working with U.S. Navy engineers have developed and tested new fire protection concepts and techniques for aircraft hangars. Early hangar fire protection systems used overhead deluge water sprinkler systems activated by pneumatic rate of rise heat detectors. With the development of aqueous film-foaming foam (AFFF), the old systems were upgraded to include overhead AFFF deluge sprinkler systems along with supplementary under wing foam monitor nozzles. New research and testing identified water spray effects on AFFF foam and a new AFFF nozzle design was developed that can be installed in hangar floor trench drain installations. Prototype nozzles were evaluated for spray pattern performance and reach. Optical fire detectors were also evaluated. The tests include the performance of a new AFFF foam product, foam nozzles and optical fire detectors. The test results were used to develop a performance specification for detector response to fire and immunity to false alarms. Application of new fire detection and suppression techniques increases hangar fire safety, save aircraft when a fire becomes evident, employee lives, while reducing inadvertent activation of suppression system. Thus saving time and expense for materials and clean up. [Bokulich, F. (2001, March). Fire suppression research. *Aerospace Engineering*, p. 13.]

#### **29. Maps for Airports in Hazardous Terrain.**

Jeppesen Sanderson is now offering a new type of airport documentation for pilots. It includes aerial photos of the airport and of all runway approaches for pilot familiarization with

hazardous terrain warnings in the area. The new document allows airlines to prequalify pilots to land at airports in areas of hazardous terrain and in busy terminals. The new charts are standard Jeppesen size. Overview page shows aerial view of airport with a terrain chart below in which high terrain is identified and color keyed. The reverse side of the chart includes a description of terrain and weather the pilot might encounter. The second page includes a photo taken while on approach. [Aviation Week & Space Technology Editors. (1995, July 10). Jeppesen profiles airports in hazardous terrain. *Aviation Week and Space Technology*, p. 38.]

### **30. Computer Simulation.**

New engineering computer program tooling provides the designer/engineer with the integration of actual test data with virtual prototypes to optimize durability, acoustics, vibration, dynamic performance of product, engineering cost reduction, and shorten time to market. Improved interfaces with other CAE products enhance durability, vibro-acoustics, and system optimization makes possible the analization of multiple design concepts and optimize product performance in a single day. Speed improvements of 10-100 times for certain application can be achieved. [Aerospace Engineering Editors. (2001, March). A look At computer simulation. *Aerospace Engineering*, p. 25.]

### **31. CFD Design Software.**

AEA Technology has released a new version of its CFD software designed to significantly shorten engineers computing design time. CFX-5 combines direct CAD import, automatic adaptive meshing, and CFX's unique Coupled Algebraic Multi-grid revolver which solves flow equations simultaneously. The new product reversion extends CFX-5 capabilities to multiphase flows. Multiphase flow module provides faster processing speeds in predicting chemical engineering process flow. Within the software resolver, linearized momentum and continuity equations are solved simultaneously for velocity and pressure. [Aerospace Engineering Editors. (2001, March). CFX family. *Aerospace Engineering*, pp. 26-27.]

### **32. E-Commerce.**

The advent of e-marketplace could reshape the business cost and operation side of the aerospace industry the same way as the hub and spoke system revolutionized the network and revenue models through unprecedented operational efficiencies. Aviation X Inc. believes the \$350 billion dollar aviation industry is particularly fertile ground for dramatic growth. The article identifies the value of online hubs to both aircraft buyers and sellers, parts/services will increase exponentially as more join, just as the hub and spoke system greatly increased airlines' ability to serve more origin/destination combinations. Two types of online hubs: vertical (industry centered) and horizontal product can be supplied to variety of industries. The hubs aggregate buyers & sellers by offering a range of mechanisms (auctions, catalogues) to mediate transactions. The more hub players increase the competition. Fifty percent of "E" conducted transactions are between buyers and sellers who have never done business. Online hubs enable sellers to learn more about market demand thus better match production to demand. Buyers have the exposure to larger supply base therefore driving down prices. [Ponticel, P. (2001, March). E-commerce, *Aerospace Engineering*, pp. 36-42.]

### **33. Rapid Prototyping.**

To minimize costs of wind tunnel testing, USAF Arnold Engineering Development Center is employing new techniques of rapid prototyping. Selective Laser Sintering (SLS) and Stereolithography Apparatus (SLA) which uses CAD files to create a small-scale physical component SLS uses powder material (microbeads) and a computer driven laser. The laser fuses the microbeads together in successive layers to construct a 3-D component. The process is designed to make models for wind tunnel testing. The model is built from a liquid material at .005 - .006 inches per laser pass. As laser passes over the liquid layer it fuses or hardens the new liquid material. [Bokulich, F. (2001, March). AEDC explores various rapid prototyping methods. *Aerospace Engineering*, p. 14.]

### **34. Heated Floor Panels.**

Dunlop Aviation Ice Protection and Composites (DAIPC) is using heated technology from its electro thermal aircraft floor panel deicing equipment for pilot and flight crew applications on next generation of Nimrod MRA maritime reconnaissance aircraft. The new panel combines plastic composites with encapsulated electrical elements. Upper surface are given an anti-slip coating. A predetermined temperature is maintained automatically. Electrical power from the aircraft is used as the energy sources. [Birch, S. (2001, January/February). Heated floor panels. *Aerospace Engineering*, p. 11.]

### **35. New Anechoic Chamber.**

A new test facility designed and built to evaluate the installed performances and electromagnetic capabilities of airborne-ground based systems in a controlled and interference free environment. The chamber has an elliptical shape to maximize use of space, lined with radar wave absorbent foam pyramids impregnated with carbon that eliminate radio reflections during testing. The chamber is in a shielded enclosure to prevent extraneous signals entering or exiting the facility. It is sized to accommodate the current range of rotary and fast-jet vehicle platforms. The facility is currently being used to assess electromagnetic medical equipment fitted to large military aircraft. This new facility design enables a large radio frequency (RF) quiet zone, but eliminates the need for complete radar absorbent material flooring, which helps reduce setup times and costs. [Birch, S. (2001, January/February). New anechoic chamber. *Aerospace Engineering*, p. 10.]

### **36. New Wind Tunnel Blades.**

Scaled Technology Works has been awarded a contract to design and produce 200 composite wind tunnel blades. The upgrade will incorporate several new enhancements into the tunnel architecture, improving aerodynamic efficiency and reduce blade maintenance costs. The blades will be manufactured by manual lay-up process using fiberglass/epoxy pre-preg material. Blade skins will be laid over a structural foam core from General Plastics. Precise aerodynamic, geometric tolerances will be met using graphite-epoxy composite tooling. The most significant change will be the design of the laminate to allow for new materials and processes to be used. New improved blades will be manufactured from this process having a more tightly controlled outer surface because of more robust materials. It will have a greater tolerance to damage. [Bokulich, F. (2001, January/February). Boeing To get new wind tunnel blades. *Aerospace Engineering*, p. 12.]

### **37. Engine Trend Monitor.**

Shadin's Engine Trend monitor is standard equipment for all new TBM-700 aircraft and is STC'd for Bell helicopters, King Airs, Cessna Caravan, Pilatus, and Piper propjet. This new aircraft engine instrument monitor combines the functions of DIGIFLO fuel /air data computers, and track engine parameter performance for the pilot and aircraft maintenance. The monitor automatically records information and downloads to a data key which can be transferred to a personal computer for evaluation and flight record documentation by maintenance entities. [Benoff, D. (2001, March). Engine trend monitor. *Aerospace Engineering*, p. 104.]

### **38. Wire Harness Testing.**

TWA has chosen Spectrum Technologies for its new mobile engine wire harness testing applications at its overhaul facility. The new system will be used to test electrical integrity and functionality of aircraft engines and associated electrical components on the entire commercial fleet. The unit is designed to operate 16 hours a day seven days a week. The test system features a four-wire resistance measurement capability as well as insulation testing up to 1000 MW at 1500 Volts dc. The system also is able to provide 115V, 400Hz AC, and 28 vdc programmable power outputs at up to 10 amps. The unit offers two and four wire Kelvin measurement testing with typical voltages of 100V, 500V, 1500V and 4000V ac and dc. The system is operated using the latest Windows Platform, and shares information with other manufacturers software. System also incorporates an intelligent self-learning function enabling new tests to be conducted more quickly. [Bokulich, F. (2001, January/February). Wire harness testing. *Aerospace Engineering*, p. 13.]

### **39. Terrain Awareness and Warning System (TAWS) Computer.**

Sandel Avionics has developed and introduced a Class-A Terrain Awareness and Warning System (TAWS) computer with a self-contained, integrated color display for pilots. The integrated display eliminates the need to share radar, Electronic Flight Instrument System (EFIS), or weather display data, and requires minimal crew training. TAWS will be an FAA requirement by March 2005 in most fixed wing turbine aircraft with a seating configuration of six or more seats. Sandels TAWS will meet the requirements of both Class-A 121 operators as well as Class-B 135 and 91 operators. A three inch edge-to-edge display technology provides a practical screen viewing area that equals larger 4 inch multifunction EFIS displays. Indicator fits into already existing three inch panel cut outs. The TAWS features an integrated color display, two-pointer RMI, and terrain/runway data base in a three inch ATI package. System includes a new RMI/TAW instrument panel package. TAWS provides a forward looking predictive terrain conflict warning by comparing its terrain data base to position information from inter connected GPS receiver and current altitude data. [Bokulich, F. (2001, January/February). Terrain awareness. *Aerospace Engineering*, p. 14.]

### **40. Aircraft Coating Facility.**

Lockheed Martin's robotic coating facility expansion is underway in anticipation of F-22 Raptor production. The new manufacturing facility technology provides the final exterior finishes for the aircraft. Two large coating bays within the facility house a robotic system that applies advanced coatings to aircraft. New coatings were designed to contribute to aircraft stealth capability. The new robot system follows a cable embedded in the floor coating which allows a track guided robot to move around the perimeter of aircraft for a more precise paint application.

[Bokulich, F. (2001, January/February). Coating facility for F-22 raptor. *Aerospace Engineering*, p. 15.]

#### **41. Airframe Noise Visualization System.**

Because aircraft noise limits continue to become more strict, NASA engineers have developed technologies to reduce aircraft noise. A new computer system has been developed to identify sounds produced by aircraft components and depicting them as color images on a computer screen. NASA tests have been able to pinpoint loud preventable aircraft flight sounds more easily, raising the prospects of quieter aircraft. Using an array of 70 microphones inside a wind tunnel wall linked to a computer, engineers viewed vivid color images of landing gear wind sounds during take-off and landings. Once sounds are identified, engineers can look at new airframe designs using an additional computer tool in the design process. Plans to test the new computer sound system will use a quarter scale commercial aircraft wing. These tests will be conducted in NASA Ames 40x80 ft wind tunnel. [Bokulich, F. (2001, January/February). Visualizing airframe noise. *Aerospace Engineering*, p. 16.]

#### **42. Helicopter Paint Coating.**

The U.S. Navy is currently studying a new environmentally safe paint coating for use on its helicopter fleet. The new paint exceeds EPA requirements for volatile organic compounds (VOC) of 3.5 lbs of VOC per gallon. The new paint has zero pounds of VOC compounds. The new coatings eliminates the use volatile organic compounds among other chemicals targeted by the Federal Government for reduction and elimination. The zero VOC paint products were produced by Deft Coatings, Inc. Deft is exploring the use of their product with other customers. Government and airline operators are potential users for environmental friendly paint application process. [Bokulich, F. (2001, January/February). Helicopter coating trial. *Aerospace Engineering*, p. 17.]

#### **43. Low Altitude Wind Shear Models.**

Controlling aircraft at low altitudes can present a difficult and complicated challenge to pilots, particularly when wind shear occurs. To better understand this dangerous phenomenon, simulations on two types of low-altitude wind shear – microburst and mountainous air stream – were conducted. Wind shear computer modeling using 2-D & 3-D Doublet modeling depicted micro-burst streams and vortex pairs at low levels. [Zhongwen, H., Xiaoli, L., Yong, D. (2001, January/February). Low altitude wind shear. *Aerospace Engineering*, pp. 20-22.]

#### **44. Advanced Fighter Exhaust Systems Simulation.**

Using advanced computer simulation models for both conceptual and preliminary design of advanced fluidic thrust-vectoring exhaust system for the next generation fighter, Lockheed Martin saved an estimated \$750,000 in development costs. Development of this concept required intensive investigation of the effects of internal nozzle contour, injector geometry, and flow properties on performance. Evaluating these effects using conventional physical testing would have required building a considerable number of test entries. Computational fluid dynamics was used to simulate the performance of many alternative designs to optimize vectoring performance, saving engineering and manufacturing time and money. Design cycle compression utilized a semi-automated grid software package called Gridgen from Pointwise was used. Gridgen utilizes a unique hierarchical grid generation method that enables engineers to quickly define grid-



blocking strategy. [Miller, D., & Yagle, P. (2001, January/February). Simulating advanced fighter exhaust systems. *Aerospace Engineering*, pp. 28-29.]

#### **45. Aircraft Hydraulic Systems Modeling.**

Computer program simulations of complete aircraft hydraulic systems has seldom been undertaken. Systems can be large and complex presenting problems for both engineering model creation and analysis. A new data management program was developed by Honeywell Normalair Garret Ltd. (HNGL), in conjunction with Flowmaster Intl. to address the large hydraulic models. HNGL developed mathematical models of complete Nimrod MRA4 aircraft hydraulic system capable of predicting system level dynamic performance and thermal performance, allowing accurate sizing of oil coolers and simulating component interactions such as effect of pressure spike on gear up locks. Included in the model was a design tool for troubleshooting during certification and assisting with the analysis of any in-service problems as well as the evaluation of future modifications. [Roland, P., Longvill, M., & Austin, K. (2001, January/February). Modeling aircraft hydraulic systems. *Aerospace Engineering*, pp. 33-35.]

#### **46. Intelligent Tires.**

Goodyear is producing "intelligent tires" for the Joint Strike Fighter (JSF) program. A transponder is embedded in the tire rubber which includes a pressure sensor and integrated circuit. The new device enables better prognostic and health management of the JSF system by monitoring essential information. A transponder senses and transmits inflation pressure, temperature, and tracks a unique tire serial number to help monitor the tire from cradle to grave. This new electronic application will record and provide maintenance with real time operational wear data for aircraft tires from cradle to grave. [Benoff, D. (2001, January/February). Intelligent tires. *Aerospace Engineering*, p. 38.]

#### **47. Fuel Leak Detection System.**

New fuel leak detection systems by Vista Research Inc. are being installed at several Canadian airports. The Leak detection system conducts fuel line pressure tests and takes into account changes in fuel volume due to temperature variations. Vista equipment can be permanently installed and designed to test pipeline systems as often as daily or a mobile version can be used periodically. Leaks can be detected as small as .00214% of the pipeline volume within a three hour test. The system works by calculating the expected change in volume as outside ground and air conditions cause temperature changes in the pipeline fuel. If fuel volume does not change in accordance with expectation, it is an indication of a leak. Two systems are available. One for underground pipelines containing more than 3000 gals, and one for truck loading racks and medium-length lines up to 10,000 gals. This new technology provides airport operators with a fast evaluation and detection of underground fuel pipelines. Quick response to an underground fuel leak will save time and money in EPA required fuel spill cleanup processes therefore reducing environmental issues. [Bokulich, F. (2001, June). Fuel leak detection system by Canadian airports. *Aerospace Engineering*, p. 10.]

#### **48. New Technology Aircraft.**

Boeing Co. has announced plans to develop a faster, long range commercial transport. The airplane will fly at speeds of Mach .95 or faster over extended ranges. It will allow passengers to fly when and where they want to, and directly to their destinations, avoiding congested hubs and

the hassle and delay of intermediate stops. [Bokulich, F. (2001, June). Boeing looks at speed and range. *Aerospace Engineering*, p. 11.]

#### **49. New AOA Transducer for C-5.**

Ametek Aerospace will provide a new angle-of-attack (AOA) transducer design to Lockheed Martine for the Military C-5 Galaxy Avionics Modification program. AOA transducer is a fuselage mounted precision sensing device designed for the angular measurements of local airflow. The transducer will provide pilots with critical angle of attack and stall warning information. Each transducer will feature a built in regulating deicing/anti-icing sensing element. It will also contain a self-compensating viscous damper to minimize flutter effects and enhance aerodynamic response. Precision adjustable gearing minimizes any hysteresis error while the balanced assembly offsets gravity and cross axis acceleration. The system requires no calibration other than alignment. Sensing vane wedge assembly is field replaceable from outside the aircraft. [Bokulich, F. (2001, June). Ametek makes AOA transducer for C-5. *Aerospace Engineering*, p. 13.]

#### **50. New Fuel Nozzle For AE 3007 Turbofan.**

Goodrich Delvan Division has manufactured a new low maintenance, long life fuel nozzle for the Rolls-Royce AE3007A1E turbo fan engine that powers the Embraer regional jet aircraft. The new fuel nozzle will provide airline operators with a component that allows for on wing, maintenance free 10,000 hour intervals and 30,000 nozzle life spans. This new fuel nozzle technology reduces operating costs, increases reliability, enhances performance, and addresses environmental concerns. [Bokulich, F. (2001, June). Goodrich fuel nozzle for AE 3007 turbofan. *Aerospace Engineering*, p. 14.]

#### **51. Direct Voice Input.**

B.A.E. Systems looks to Direct Voice Input (DVI) to address cockpit (pilot) ergonomic concerns for the Eurofighter Typhoon. DVI is likely to become an increasingly important aspect of cockpit future ergonomics. It is a natural, intuitive, and has the ability to manage non weapons systems within the aircraft. Cockpit instrumentation consists of typical glass-cockpit HUD hardware/software packages. DVI systems can be used to control head down displays, organizing attach profiles, target assignment, and display changes. DVI is typically used in a high workload but lower dynamic situations. DVI systems are coupled with equivalent physical operations for dual application and safety. DVI sound recognition is 85-90% in test phase. New algorithms increase sound/word recognition. [Birch, S. (2001, June). Eurofighter ergonomics. *Aerospace Engineering*, pp. 18-20.]

#### **52. Aircraft Structural Integrity Tracking.**

Individual aircraft tracking program developed by Raytheon E-Systems ensures long-term structural integrity and airworthiness of the aircraft. New system uses a flight director recording system and strain sensors to identify and record structural airframe/engine loads. Information downloaded to ground based maintenance systems for fatigue crack growth analysis and results received will be used to make airframe/engine inspection and maintenance recommendations. FDR systems consists of eight line replaceable units (LRU), signal acquisition unit, data transfer unit, engine signal data converters, tri-axial accelerometers, and flight data panel. Eight strain sensors bonded to critical fatigue spars are used for data acquisition. Engine and structural data

downloaded to ground base units via data transfer units for processing and analysis. [Aerospace Engineering Editors. (1997, April). Aircraft structural integrity tracking. *Aerospace Engineering*, pp. 11-14.]

### **53. PC-Aided Design.**

A new computer engineering design program was developed by the University of Kansas under a NASA contract to provide new GA-CAD design tools for the General Aviation manufacturing industry. The new software is user friendly and allows designers to assess the performance, structural weight breakdown, and stability control characteristics for new airplane configurations in one software package. The program runs on a PC and gives designers the capability to design, draw, and analysis capabilities in one single program. The package contains 10 modules. They are: weight, aerodynamics, performance, geometry, propulsion, stability, dynamics, loads, structures, and costs. General Aviation aircraft designers now have the ability to design and develop new technology aircraft (like that of larger aircraft designs), therefore reducing design time costs, increase design alternatives, improve aircraft performance, product quality, and significantly improve manufacturing competitiveness. [Anemaat, W., & Roskam, J. (1997, April). Designing general aviation aircraft using a PC. *Aerospace Engineering*, pp. 22-24.]

### **54. New Aerospace Materials.**

Materials for aerospace applications must be able to operate in often demanding environments. New aircraft construction materials consist of alloy used for super plastic forming of complex shapes, metal matrix composites for engine blade applications, quartz materials for radomes, electronic component coatings, and nano-powders to improve conventional materials. The use of new materials and applications reduce component weight, increase component strength and life expectancies, be able to withstand greater stresses (temperatures and pressures) decreases manufacturing time lines, reduces costs. [Trego, L. (1997, April). Aerospace materials. *Aerospace Engineering*, pp. 31-35.]

### **55. Biometric Handreader.**

The biometric handreader provides airport security officials with the capability of identifying individuals by hand size and shape ensuring that only authorized personnel are allowed in secured areas. The system offers a positive, nonintrusive, and transferable means of identification. This new technology enables facility entry and egress to be monitored, and electronic logging system allows a company to track visitors, contractors as employees. Added benefits include employee work/time/attendance record keeping. [Aviation Week & Space Technology Editorial Staff. (2001, November 26). Biometric handreader. *Aviation Week & Space Technology*, p. 82.]

### **56. Simulation Software.**

A new simulation software program DADS by CAPSI was used by Gulfstream to obtain Russian certification for the GIV SP model aircraft. The particular application using the new DADS software was the landing gear assembly and its capability of withstanding rough runway conditions typical of Russian airports. The DADS software was used by the manufacturer to assemble, simulate, and animate the GIV landing gear system. Specific utilization concerns hovered around the landing and taxi stresses of the gear assembly. The software package

incorporates the flexibility of component applications, closed and open loop systems typically of oleo-pneumatic strut performance. The use of this new software tool saved 3-6 months of certification time and \$100,000 in costs. [McKissak, D. (1997, April). Simulation software aids in jet certification. *Aerospace Engineering*, pp. 42-43.]

#### **57. New Deicing System.**

B.F. Goodrich Aerospace has developed the SMARTboot system ice detection and protection system. The system integrates current pneumatic deicer technology with a new wide-area detection monitor package. The package provides the pilot with the monitoring capability up to three linear feet along the deicer boot assembly. The system provides multipoint ice sensors in which case single point applications may not totally identify icing conditions. When the aircraft enters icing conditions, it will notify the pilot of ice accretion, and when to activate system, and notification of system operation and function. [Trego, L. (1997, April). Deicing system. *Aerospace Engineering*, p. 40.]

#### **58. Active Noise and Vibration Control.**

Lord Corporation received FAA approval for the NVX active noise and vibration control system. The system will be installed on McDonnell Douglas DC-9 and MD80 series aircraft. The system is designed to eliminate noise due to engine vibration typically around the 20db and above background noise. System detection actuators are mounted on the engine mount yoke and counteract engine vibrations. The system controller updates commands to actuators instantaneously to adjust for changing flight conditions. Microphones behind cabin panels and under floor deliver continuous data to controller for algorithm updates therefore reducing pilot and passenger noise reduction. [Trego, L. (1997, April). Active noise and vibration control. *Aerospace Engineering*, p. 47.]

#### **59. New Propeller Blades.**

A new propeller designed by Hartzell incorporated a scimitar-like plan form being investigated by a UK manufacturer for its Britten-Norman aircraft models. The UK program is investigating new propeller designs to reduce noise impact of general aviation aircraft. The new propeller supplied by Hartzell uses new aerodynamic and acoustic design techniques developed under a NASA contract. Enhanced airfoil efficiency will result in the same power transfer to the aircraft at reduced engine speeds. New propeller design applications are focused for law enforcement applications that require minimum aircraft noise parameters. [Birch, S. (1999, November). Scimitar propeller blades for the islander. *Aerospace Engineering*, p. 5.]

#### **60. New Instrument Panel Lights.**

A new range of aircraft instrument panel lights have been developed featuring legends that remain hidden until illuminated by light emitting diode (LED's) located in the printed circuit board behind the plastic fascia. These new instrument panel lights have been developed by TEC Electrical Components. The new design meets MIL-D 7788F type specification. The lights are resistant to shock and vibration loads. Circuit boards are removable for servicing and repair. LED technology allows the generation of high brightness levels with low heat. Panel lights for each respective system will light up when the circuit is activated by either a test function or an operation by the pilot. Otherwise there is no visible indicator on the panel. [Birch, S. (1999, November). New instrument panels, *Aerospace Engineering*, p. 15.]

### **61. Supply Chain Management Solution.**

Airbus wing assembly facilities have begun using Waer Systems Inc software. The WaerLinz system is used to streamline the supply of small components. Software was developed to provide detailed and transparent data to areas involved with manufacturing procurement, supply, and stocking of all fastener types used in wing construction. The System based on a “Pull” philosophy with modules allowing integration with local master production schedules. Static inventory levels monitored at every stage, controlled, minimized on a part by part, bin by bin basis in accordance with usage, product variances, and cost. Therefore preventing overages and excess inventory. The new software handles over 4400 part numbers available from 8,000 bins throughout the manufacturing facility. The bins are designed containing two bags. One bag is for “in-use” and the other for “reserve”. Parts labeled so a hand held scanner can read bar code and information fed into the main computer system for processing and replacement orders. [Bokulick, F. (2001, May). Airbus institutes supply chain management solution. *Aerospace Engineering*, p. 14.]

### **62. Airport Management Area Safety System (AMASS).**

The FAA deploys its new Airport Management Area Safety System (AMASS) at two major airports for runway incursion detection. This new tool is a complex hardware/software suite that combines predictive software with surface and airspace radar data, providing ATC controllers an additional level of incursion protection. When the program is tripped, AMASS generates an audio and computer screen alert to controllers when a threat should occur. AMASS units include controller display monitors, terminal automation interface, and support units. Conflict predictions rely on ASR-9 radar covering airborne aircraft at 200 feet or less and 6,000 feet of runway threshold. [Craft, J. (2001, June 4). FAA deploys new safety alarm system. *Aviation Week and Space Technology*, p. 54.]

### **63. Dry-Transfer Application Aircraft Markings.**

Graphicraft has developed a new dry-transfer application process. Process is appropriate for engineering and warning markings. New system is applied dry and over lacquered to achieve original equipment finish. Users of this new application are government, manufacturers, and maintenance entities. New dry transfer technique uses a very thin material designed to ensure a flush fit to any aircraft surface including graphics. New technology dry transfer marking system applications provides ease of application, durability, and appearance. Reduces application pre-work, improves looks, and reduces costs. [Birch, S. (2001, May). Fit-and-forget aircraft markings. *Aerospace Engineering*, p. 6.]

### **64. Electro-Thermal Prop Deicer.**

Quick disconnect system for electro-thermal prop deicer kit developed by BF Goodrich Aerospace allows ease of installation and field replacement by technicians of the prop deicer electrical leads. The new kit uses an approved electrical disconnect plug with replacement tie straps. New and improved bracket design simplifies propeller balancing. [Benoff, D. (2000, April). Prop deicer. *Aerospace Engineering*, p. 30.]

#### **65. New Aircraft Window Wipes.**

Dupont Sontara introduced their new window wipe products designed exclusively for use by ground personnel on aircraft windshields and passenger windows. The cleaning wipes are manufactured with tiny apertures in fabric that creates absorbent channels that pull away dirt and grit from window reducing scratching sensitive surfaces. The wipe design was approved by Boeing and is included in their window assembly document. [Business & Commercial Aviation Editorial Staff. (2001, August). Aircraft wipes. *Business & Commercial Aviation*, p. 114.]

#### **66. MX20 Multifunction Display.**

UPS Aviation Technologies MX20 multifunction display (instrument that provides route info coupled with ground mapping, weather and traffic) has received FAA certification. System notifies pilot when aircraft is close to ground. Instrument provides terrain mapping and issues pilot an advisory if aircraft is within two minutes of encountering terrain. The system continuously monitors aircraft altitude, position, ground speed, route of flight and compares data to terrain elevation data base. Color coded displays depicting red for terrain at or above aircraft, yellow for terrain within 500 ft and green for 500-2000 ft below. The flat panel display consists of a 65,000 color instrument with four times visual resolution of other displays. The MX20 is capable of showing automatic dependent surveillance broadcast (ADS-B) traffic reports, standard navigation symbols for VOR's, NDB's, intersections, and special-use airspace. [Aerospace Engineering Editors. (2000, May). MX20 display FAA certified. *Aerospace Engineering*, p. 10.]

#### **67. Flight Situation Multifunction Display.**

Avidyne Corp. has developed its third in the model series of their pilot flight situation display. The unit interfaces with weather radar, ground proximity warning, traffic alert, collision avoidance system, and skywatch traffic alert. The MFD unit interfaces with Collins WXP 250/270/270A/300, Bendix RDR 1100/1200/1300 radar system, and BF Goodrich skywatch traffic advisory system. It also interfaces with Honeywell's ground proximity warning system and storm scope capability. [Bokulich, F. (2000, May). Advanced multi function display. *Aerospace Engineering*, p. 8.]

#### **68. Lightning Warning System.**

A French company called Dimensions has launched its SAFE lightning warning system for various aerospace industries. The warning system was developed to predict lightning risk in the area under surveillance. The system designed for aerospace organizations, European Space Center, Indian Space Center, BAE Systems, British Royal Navy, and French Army. It measures the electrostatic field at ground level at thunderstorm onset, follows its evolution, and detects intra-cloud and cloud to ground lightning. It detects thunderstorms to a range of 30 KM and lightning up to 9 KM away at temperatures between -25° to 55° C. Potential users of this technology are ATC, airports, and airline operations. [Birch, S. (2000, May). Lightning warning. *Aerospace Engineering*, p. 16.]

#### **69. Eight Screen Glass Cockpit.**

The new Airbus A3XX-555 double deck aircraft will have eight-screen glass format cockpits instead of usual six. The eight screen layout is built around large interactive controls and displays

that encompass former MCD4 and two data communication display units DCD4. The new system interaction function will permit flight crews to select and enter information using a pointing device similar to a PC mouse. Pointers mounted on pedestal. Use of larger screens allows better integration of vertical display with the ability to visualize aircraft data. Future system additions will include video cameras for taxi assist. Also, aircraft would have facility to display airport maps showing position. [Birch, S. (2000, May). Eight-screen A3XX. *Aerospace Engineering*, p. 18.]

#### **70. New Manufacturing Machine for Producing Hydraulic Cylinder Blocks.**

Dunlop Aviation Braking Systems has introduced a new manufacturing machine for producing hydraulic cylinder blocks. New machine has significantly reduced manufacturing lead times by 73%. Machine and manufacturing processes also experienced a significant reduction in large number of different billets needed for machining by older methods. Dunlop installed a Matsura MAM-72M multi parallel machine that eliminates machine “set-up” time. The new system utilizes a high-speed spindle facilitating the adoption of the latest tooling, while prismatic machining allows several operations to be combined. [Birch, S. (2000, May). Cutting-edge technology from Dunlop. *Aerospace Engineering*, p. 19.]

#### **71. New Borescope Technology.**

A new 3-D stereo measuring technology has been developed by Olympus Industrial Products, for the measurement of tiny defects in turbines, compressors and other components. Technology developed to overcome problems found in conventional measuring systems that provided skewed results due to surface contours angles, and distance to scope of the part in question. The new system provides technicians with “point and shoot” measurement ease with repeatable accurate inspector results. Stereo measuring also allows inspectors to make multiple measurements on a single image. This new system can measure point-to-point, line-to-point, and line-to-line damages. System can regenerate damaged areas on the screen and calculate mass loss easily. [Bokulich, F. (2000, June). New bores copy technology. *Aerospace Engineering*, p. 11.]

#### **72. Electric Constant Speed Prop.**

A new electric, constant speed, three blade propeller from MT-Propeller, Entwicklung GmbH, has received LBA certification per STC for the Cessna 172R and S models. This modification allows for the use of a low noise propeller that abides with German noise rules. The new propeller has a dB (A) limits between 7.8 and 8.6 below the lowest noise limits in Germany. [Bokulich, F. (2000, June). New prop receives German certification. *Aerospace Engineering*, p. 15.]

#### **73. Improved Fuselage Crashworthiness.**

Design goals for light-aircraft crashworthiness are limited to impact forces transmitted to the pilot and passengers and instructional integrity of the fuselage for minimum safe occupant volume. In 1997 NASA initiated a research program to develop a fuselage concept for potential light aircraft. The research program identified an energy absorbing fuselage concept of four structural regions: upper fuselage cabin, frangible outer shell, primary floor structure, and energy absorbing sub-floor beams. Materials used throughout the project design consisted of composite fabric, composite/sandwich structures. New technology materials applied to new aircraft structural designs increases the survivability of pilots and passengers in a crash simulation.

[Jackson, K. E., & Fasanella, E. L. (2000, June). Improving fuselage crashworthiness. *Aerospace Engineering*, p. 31.]

#### **74. Cockpit Display of Traffic Information (CDTI).**

To improve safety and achieve smoother running operations of air traffic management, researchers at Georgia Institute of Technology are developing an enhanced cockpit display called "Cockpit Display of Traffic Information (CDTI)". It is designed to allow pilots to see other aircraft in the area and quickly realize the distance between aircraft. CDTI would allow controllers to give higher types of commands and communicate more directly with pilots. [Birch, S. (2000, September). How much is too much. *Aerospace Engineering*, p. 20.]

#### **75. Flight Crew Operation Software.**

Boeing has introduced a new software package that optimizes airplane performance calculations, reduces pilot workload, increases efficiency, and dispatch reliability of flight operations. The new Boeing Laptop computer tool is a software application designed to increase operational efficiencies by optimizing takeoffs and landing calculations. It provide quick access to digital aircraft manual along with customized data for individual airplanes allowing higher levels of accuracy for payload capacity as aircraft performances in any weather condition. [Bokulich, F. (2001, August). Boeing develops flight crew operation software. *Aerospace Engineering*, p. 23.]

#### **76. New Radome Material.**

Avcom Technologies is exploiting a new foam core material in aircraft radomes that features superior transmissivity and physical toughness. New radomes aim to improve the performance of wind shear radars and traffic alert and collision-avoidance systems. New material benefits from the highly hydrophobic qualities of the patented nanosil surface. Nanosil surface keeps the water from adhering to the surface. Testing shows nearly 100% improvement in transmission efficiency in heavy rain. New radomes have the same thickness as current nomex examples, and are structurally better and cost competitive. [Aviation Week & Space Technology Editorial Staff. (2001, May 21). New radome better in rain. *Aviation Week & Space Technology*, p. 96.]

#### **77. Icarus Real-Time Cockpit Instrument Display.**

The Defense Evaluation and Research Agency has developed Icarus, an advanced and real-time cockpit instrument display system to aid post-crash investigation analysis. The system facilitates "rapid assessment" of black box data. The systems visualize data rapidly in real-time using a dynamic graphical software expertise of TENET systems. Software will accelerate process of incident investigation and make clear all stages of aircraft flight. Data input can be extracted from black box recorders or transmitted via telemetry downlink to ground based systems enabling display of instrument reading on simulated flight deck screen in real time. This technology application allows rapid assimilation of behavior/events involving accidents, and provides black box data to investigators in the field. It has potential use as a debriefing tool for pilot training. [Birch, S. (2000, December). No melting moments for Icarus. *Aerospace Engineering*, p. 14.]



### **78. Diesel Engines for GA Aircraft.**

Aerospatiale/Matra and Renault Sports partnership created a new diesel engine for general aviation aircraft. New diesel technology is applied to aircraft designs because of limited availability of 100LL Avgas. The new Diesel powerplant design was subjected to initial test flight in March 1998. The powerplant flew 40 hours reaching a maximum altitude of 25,000 ft. Over 1900 test hours have been accumulated covering the entire projected power ranges from 180-200 HP. The new Jet A diesel engine design will change the way GA aircraft will operate by the pilot owner. It will also affect how the aircraft will be designed using materials compatible to kerosene instead of AV gas. This will require a change in training and maintenance protocols. [Aerospace Engineering Editorial Staff. (2000, December). New diesels for GA aircraft. *Aerospace Engineering*, p. 35.]

### **79. Inflatable Aircraft Passenger Restraint System.**

BF Goodrich Aerospace has developed an inflatable restraint system for the increase protection of passengers of all sizes from small children to large adults. The inflatable system designed to position and restrain passengers in their seat limiting forward movement during a crash. It deploys from the lap belt rather than at the head. The restraint system removes seat belt slack and restrains the upper body keeping it from forward head contact with fixed objects. The system meets 16g regulation and distributes loads on the passenger and seat at a reduced rate. [Aerospace Engineering Editorial Staff. (2000, December). New restraint system for improved passenger safety. *Aerospace Engineering*, p. 37.]

### **80. Infrared Aircraft Deicing.**

Radiant Energy Corp. has developed the Infratek Deicing Service Center for large commercial aircraft operators. The facility is a taxi through preflight ground deicing system that uses targeted infrared energy to melt ice and snow from aircraft surfaces. The system uses an array of energy processing units housed in a large structure. Computer controlled systems select and direct the correct amount of infrared heat for specific aircraft applications. Infrared rays strike the aircraft surface and simulates surface molecules causing them to move more rapidly therefore melting ice and snow. This new aircraft deicing technology eliminates glycol liquid products for deicing use saving costs, time, and clean-up. [Aerospace Engineering Editorial Staff. (2001, July). Infrared deicing gaining acceptance. *Aerospace Engineering*, p. 12.]

### **81. Integrated Circuit Time of Flight Measurement System.**

Sandia National Laboratories has developed a new integrated circuit capable of measuring time of flight accuracy of 125ps to record critical timing of signals in weapon test flights. New telemetry systems require a compact, lightweight low power circuit device. The circuit uses a pulse stretcher technique to increase resolution up to 200 times for a low power electronic clock. The circuitry also provides greater resolution by lengthening the duration of output signal 64-200 times longer than the input signal. Techniques could be compared to recording an event with fast action film and playing it on a slow speed. The new integrated circuits are designed to operate in extremely rugged and harsh environments. [Bokulick, F. (2001, July). Integrated circuit measures time of flight. *Aerospace Engineering*, p. 7.]

## **82. Materials for Lightning Strike Protection.**

Jet aircraft structures are often constructed of carbon fiber composites of which some external skin-form parts of the fuel tank. A lightning strike to the tank skin is likely to cause arcing and sparking at the structural joints, therefore igniting the fuel. Therefore, new airframe designs may include a network of copper strips bonded into the composite materials. Copper strips direct the electrical charge away from the fuel. Two manufacturing techniques have been studied and tested. The first design has a copper foil bonded above the composite skin and the second has the foil integral to the composite material. Of the two designs the latter has the best load flexing and repair characteristics. [Pridham, B., Jaeger, D., & Schreiner, M. (2001, September). BAE systems and EADS explore lightning strike protection. *Aerospace Engineering*, p. 28.]

## **83. Aircraft Window Shading Device.**

Research Frontiers has developed a new window-shading device for aircraft installations. It uses a suspended particle device (SPD) to control light. SPD refers to light absorbing microscopic particles suspended between two electronically coated surfaces. The film is placed between two panes electrically coated conductive plastic/glass. The application of an electric voltage will increase or decrease the amount of light allowed through the window. When the switch is off by the passenger particles are randomly dispersed and absorb light creating a dark appearance. When switched is turned on the particles align and the glass will change from dark to clear. New SPD film window applications will reduce aircraft operating weight and increase passenger comfort by allowing them to better control window light. [Bokulich, F. (2001, July). Aircraft window shading alternatives. *Aerospace Engineering*, p. 16.]

## **84. New Intake Ice Protection System for New Technology Helicopters.**

Dunlop Aviation Ice Protection and Composites (DAIPC) has developed a new intake ice protection system for new technology helicopters. Dunlop intakes are three-dimensional composite structural moldings incorporating undercuts and compound surfaces to meet aerodynamic requirements. Electric power from the aircraft produces heat sources for anti-icing conditions. The new pilot controlled system uses a high temperature epoxy-resin/hybrid reinforcement grid with a nonmetallic honeycomb base. Component molding is via conventional hand lay-up techniques followed by autoclave curing. Resin/hardeners used are commercially available to produce high temperature operational properties. In-house manufactured resin impregnated fabric was developed using a solvent-less process. Ceramic fibers in the inlay can provide ability to meet fire barrier requirements. This new technology greatly enhances operational safety for the flight crew. [Birch, S. (2001, July). Giving ice the boot. *Aerospace Engineering*, p. 17.]

## **85. Stealth Technology.**

Inlet and exhaust systems are perhaps the most crucial components in reducing radar reflections from the front and rear of combat aircraft. Reducing inlet radar cross sectioning requires an understanding of how radar waves travel through the airframe engine inlets. Reducing radar inlet signatures requires an evaluation of frequency wavelength and duct width. Designing duct size and geometry with associated radar absorbing materials will diminish radar returns. Modifying engine exhaust cone supports or flow straighter also dampens and reflects radar returns. Hiding heat exhaust elements is critical because infrared and optical sensors are

used to identify targets. New inlet duct designs and exhaust temperature/light emission engineering concepts are key to evading radar detection and subsequent missile attack. [Dornheim, M. (2001, March 19). Components work together to cloak "shiny engine". *Aviation Week & Space Technology*, p. 92.]

#### **86. Engine Condition Health On Line Software.**

Jet-Care International has developed an on-line software package called Engine Condition Health On Line (ECHO) that quickly access quality-of-life data about aircraft engine conditions by aircraft maintenance. ECHO is the first online engine monitoring software package to provide customers with a detailed picture of an engines condition. The system uses flight data input and oil samples for evaluation of engine performance and wear diagnosis. Flight data parameters looks at the engines gas path condition while oil analysis looks at component wear data suspended in the oil. New computer evaluation technology integrated with turbine engine operating parameters provides the pilot and maintenance operations staff with updated engine performance analysis. New computer software increases flight operations safety (identifying failures) and therefore enhances economic benefits for early powerplant problem diagnosis. [Fiorino, F. (2001, March 19). Every engine tells a story' online with ECHO. *Aviation Week & Space Technology*, p. 12.]

#### **87. New Avionics and Electrical Systems for the Airbus A380.**

Thales Electronics will supply critical avionics and electrical systems for the Airbus A380. Thales will provide cockpit display systems (CDS) and variable frequency electrical power system. CDS devices will feature multi-window screens and a track ball cursor control device that will allow the pilot to interface with all display and control functions and on board systems. A 6x8 active matrix liquid crystal diode screens with a high-resolution 768x1024 color-pixel formats will be installed in the aircraft. A 370-770 Hz variable frequency electrical power generator will be used for the first time on a commercial aircraft. It will limit the complexity of the 400Hz hydro-mechanical systems and reduce weight. The new computer hardware/software application will enhance (change) pilot data acquisition processes and control functions. New power generation system will reduce aircraft operating weight. [Taverna, M. (2001, July). Thales avionics lands key A380 contract. *Aviation Week & Space Technology*, p. 42.]

#### **88. New Jet Fuel GA Engine.**

Superior Air Parts has developed a new TAE 125 piston engine built to operate on Jet A fuel. The new engine liquid cooled single power lever turbocharged kerosene fuel engine design is expected to compete with higher horsepower powerplants. This new technology engine design utilizes diesel engine technology applied to aircraft installations. Engine life increases TBO to 3000 hours and a reduction of 40% in operating expenses. New engine system will require a new pilot/technician understanding of powerplant operation. [Plane & Pilot Editorial Staff. (2001, October). GA engine on a new diet. *Plane & Pilot*, p. 12.]

#### **89. Arc Fault Circuit Interrupter.**

In-flight electrical fires are among the most feared events for pilots and passengers. Eaton Aerospace has developed the Arc Fault Circuit Interrupter (AFCI) to quickly isolate electrical faults lasting less than a millisecond in length. The Eaton circuit breaker (CB) utilizes micro electronic circuitry embedded within the CB. The AFCI system monitors and analyzes current

using algorithms that search for random fluctuations in a circuit wave form. When the processor determines an arc fault a signal is sent to a circuit protection device that then triggers a sequence that isolates the circuit. Algorithms are used in the CB circuit to provide the ability to discriminate between a “bad” and a “good” fault (normal operation of a motor). New microelectronics in CB’s provides discrimination protection between fault categories typical of aircraft systems. The new device will instantaneously sense an over current situation without sacrificing the ability to sense an arc fault. These new CB’s provide the flight crew with a better and safer protection device. [Phillips, E. (2001, April 2). Eaton developing solution to electrical faults on aircraft. *Aviation Week & Space Technology*, p. 107.]

#### **90. Highway in the Sky (HITS).**

A NASA senior executive test flew a Lancair 400 with NASA’s Highway in the Sky (HITS) flight instrumentation package. The HITS system incorporates all functions of airspeed, vertical speed, direction, attitude indication and flight pattern projection window. The HITS technology provides a stream of rectangular outlines stacked deep that gives the pilot constant updates on how to orient the airplane to stay on course. A new box outline appears every five seconds creating the feel of being able to look into the near future of where the aircraft is headed. This new LCD flight navigation computer screen technologies gives the GA pilot integrated real-time flight information showing where the aircraft is located in a 3-D space. It shows the pilot where he is going. [Plane & Pilot Editorial Staff. (2001, October). NASA lays hands on HITS. *Plane & Pilot*, p. 11.]

#### **91. Integrated Display/Sighting System.**

BAE Systems has developed an integrated display/sighting system to provide AH-1Z pilots with a visor-display day/night symbology and night vision imagery monochrome TV cameras. The system uses a special lightweight composite helmet fitted with an outer display module and visor that displays both piloting and targeting information. The outer shell houses visor and electronics to process data from helicopter mission computer. Two black and white TV cameras provide day/night targeting capability. This new helmet vision technology provides the pilot with system and targeting information using HDTV cameras capable of 1400x1800 lines of resolution and can be removed and installed with one hand. Helmet does not require heavy vision goggles mounted in front of the helmet. New system reduces weight and provides enhanced image resolution. [Aviation Week & Space Technology Editorial Staff. (2001, April). HMD forms centerpiece of AH-1Z targeting system. *Aviation Week & Space Technology*, p. 66.]

#### **92. Satellite-Based E-Mail System for Airline Passengers.**

Singapore Airlines has introduced a satellite based e-mail system for passengers and plans have fleet converted by 2002. Tenzing Communications developed the satellite system for aircraft use and it is designed to provide e-mail connectivity, web service, DVD, and games for passenger use. E-mail and web access system is connected to a Matsushita Avionics system MA 5300 in-flight instrument system. Passengers would connect laptops to standard seat jacks. E-mail would be batched and compressed by on-board servers and transmitted every 10 minutes to a Inmarsat satellite receiver than to ground stations. Up-loads would then follow. New electronics e-communication/commerce technology would be available to passengers through on-board servers and satellite connection. New concept enhances airline passenger services by using technology to allow business communication as well as pleasure entertainment. [Smith, B.,

& Dennis, W. (2001, April). Sky's no limit for e-mail as airlines add in-flight upgrade. *Aviation Week & Space Technology*, p. 55.]

### **93. Cabin Alert and Monitoring.**

Securaplane Technologies along with Hollingsead have developed a Cabin Alert and Monitoring System (CAMS) to be installed on Delta Airlines aircraft fleet. The system will permit flight crews to view activities in the cabin via cameras with low light capabilities. The CAMS utilize light-weight, low power airborne camera units coupled with a wireless alert system that alerts the flight deck about cabin situations that require their attention. [Aviation Week & Space Technology Editorial Staff. (2001, November 26). Cabin alert and monitoring. *Aviation Week & Space Technology*, p. 82.]

### **94. New High-Speed Tire for the Concorde.**

Michelin has developed a new high-speed tire for the Concorde called NZG (near zero growth). The tire is designed to withstand low and high speed applications, foreign object damage, and high stress levels. New NZG technology is based on the use of new high modulus materials that reduce structural deformation. By limiting carcass growth the rubber tread works under less tension and is less vulnerable to damage and shock. New material, design, and manufacturing technology has produced a new tire that with stands appreciable load pressures, damage resistance, less weight, greater impact damage and can operate safely under wider inflation parameters. [Aerospace Engineering Editorial Staff. (2001, August). New tire design. *Aerospace Engineering*, pp. 6-7.]

### **95. Flight Deck Track Ball Cursor Control.**

A new interactive flight deck for the Desault Falcon business jet is expected to advance the trend toward PC-like cockpits. The enhanced Avionics System (EASy) combines Honeywell's Primus Epic flight instrumentation and Dassault single engine combat aircraft in an integrated Windows environment. A novel feature of the EASy cockpit is the use of a track ball-like cursor control device mounted at the foot of the center council. The rack ball allows the pilot to point and click menu driven control systems computers. System display units (2) carry primary instruments and the remaining two provide engine and system information. Flight display indications are similar to those found on home desktop computers. New flight instrumentation technology concept represents a potential increase in aircraft safety due to pilot decreasing "heads down" time pushing buttons. System reduces workload and improves situational awareness. [Taverna, M. (2001, May 2). Falcon flight deck spotlights "track ball". *Aviation Week & Space Technology*, p. 77.]

### **96. Laptop Tool for Takeoff Performance Calculations.**

Boeing has developed software that provides PC laptop paper base information needed for calculating takeoff performance speed for any aircraft from runways at any airport. The Boeing Laptop Tool (BLT) is user friendly and provides take-off systems operation information and also landing information. BLT software works on any off-the-shelf laptops running Windows 95/NT or higher. BLT software has the capability to be customized for individual MEL item activation to reflect the operating environment. Current hardware/software platforms can be integrated with in real-time flight deck environments for performance calculations and manual data acquisition by pilots. This utilization improves pilot accuracy, increases payload capacity, and enhances

safety for aircraft specific data and performance numbers calculation. [Mecham, M. (2001, May 14). Boeing laptop tool designed to relieve pilot workload. *Aviation Week & Space Technology*, p. 97.]

#### **97. Infrared Ground Deicing System.**

Deicing has required spraying glycol on aircraft by ground personnel. Continental Airlines is using an infrared (IR) alternative at Newark Airport. The system produced by Radiant Energy Corp. called InfraTeck. After loading passengers, the aircraft taxis into a special building where IR energy is directed down to the aircraft therefore melting snow and ice. IR units consist of energy process units that convert natural gas into IR energy. InfraTeck requires eight minutes to deice an aircraft where 20 minutes would be needed for the same aircraft using glycol. [Nordwall, B. (2001, May 28). Deicing times cut with new technique. *Aviation Week & Space Technology*, p. 45.]

#### **98. High-Bandwidth In-flight Internet.**

Three U.S. carriers have tentatively agreed to partner with Boeing's Connexion business unit to bring high-bandwidth in-flight internet, e-mail, and live TV to passengers via the wireless links to laptop computers or other hand held devices. United Delta and American will outfit up to 500 aircraft with connexion local servers and Boeing designated Ku-band electrically steered transmitting and receiving antennas. User costs are projected to be \$20.00 per hour for up to 5-Mbps of incoming data including web content via Boeings' partner Screaming Media. [Craft, J. (2001, June 18). Three airlines to fly Boeing connexion. *Aviation Week & Space Technology*, p. 100.]

#### **99. Ultrasonic Ice Detection.**

Goodrich and Pennsylvania State University developed a ultrasonic guided wave sensor for ice accretion detection on aircraft wings. The system is based on ultrasonic wave propagation using transducers bonded to wing skins. Sound waves are used to identify bonding contaminants such as ice and signal computer processor for initiating ice removal procedures. The system was demonstrated during two flight trials aboard an Airbus 340 and performed to expectations. This new ultrasonic ice detection technology enhances the pilot's ability to detect more accurately ice accretion on the wing surfaces. Therefore the new system helps to maintain better aircraft performance pilot awareness during flight through icing conditions. [Hongerholt, D., Williams, G., & Rose, J. (2001, September.). Ultrasonic ice detection from Goodrich. *Aerospace Engineering*, p. 27.]

#### **100. Runway Debris Scanning System.**

The UK's Defense Evaluation and Research Agency (QinetiQ) has designed a new system for the identification of foreign objects and debris found on runways. Using a high-resolution millimeter-wave (MMW) radar, the system continuously scans runway surfaces in all weather conditions. The system is capable of distinguishing small objects from a distance of 300 meters, but a commercial version may do so from a distance of 1.5 meters. The system has the capability to be linked to an automatic alert system. Additional applications could spot wildlife runway incursions. Use of the equipment would benefit flight crew members as well as airport operators. [Birch, S. (2001, October). DERA's runway debris scanning system. *Aerospace Engineering*, p. 7.]

## Appendix B-1.

### DTIC Subject Categories.

#### 1. Aviation Technology

##### 1.1. Aerodynamics

- 1.1.1. Flight characteristics and problems of full-scale or model aircraft and their components as they are affected by the dynamics of air;
- 1.1.2. Flight testing and wind tunnel testing.

##### 1.2. Military Aircraft Operations

- 1.2.1. Military aircraft operations such as takeoff and landing, air traffic, all weather and night flight, taxiing, approach, and inflight refueling;
- 1.2.2. Flight safety; Ground safety; Aviation accident studies;
- 1.2.3. Aircraft simulators and training devices.

##### 1.3. Aircraft

- 1.3.1. Design, production, and maintenance of aircraft, aircraft components, and aircraft equipment;
- 1.3.2. Structural studies of complete aircraft components such as airframes, bodies, and wings.
- 1.3.3. Airworthiness;
- 1.3.4. Crashworthiness;
- 1.3.5. Aircraft damage assessment and vulnerability studies; effects of gunfire and blast on aircraft and flight equipment.

##### 1.4. Helicopters

##### 1.5. Bombers

##### 1.6. Attack and Fighter Aircraft

##### 1.7. Patrol and Reconnaissance Aircraft

##### 1.8. Transport Aircraft

##### 1.9. Training Aircraft

##### 1.10. V/STOL

##### 1.11. Gliders and Parachutes.

Includes paragliders and kites, for both military and civilian applications.

##### 1.12. Civilian Aircraft

##### 1.13. Pilotless Aircraft

###### 1.13.1. R.P.V.;

###### 1.13.2. Drones.

##### 1.14. Lighter-than-air Aircraft.

Airships, blimps, dirigibles, balloons, for both civilian and military applications.

##### 1.15. Research and Experimental Aircraft. Includes aerospace aircraft.

##### 1.16. Flight Control and Instrumentation

###### 1.16.1. Instruments, sensors, displays and recorders necessary for control and monitoring the flight of an aircraft;

###### 1.16.2. Cockpit and cabin display devices and onboard checkout systems;

###### 1.16.3. Onboard navigation display devices;

###### 1.16.4. Automatic pilots;

###### 1.16.5. Stability and control systems;

###### 1.16.6. Boundary layer control systems;

###### 1.16.7. Dynamic and static control devices.

##### 1.17. Terminal Flight Facilities

###### 1.17.1. Airports;

###### 1.17.2. Military air bases;

###### 1.17.3. Runways;

###### 1.17.4. Hangars;

###### 1.17.5. Ground refueling systems;

###### 1.17.6. Heliports;

###### 1.17.7. Aircraft handling and maintenance equipment;

- 1.17.8. Taxiways;
- 1.17.9. Parking aprons;
- 1.17.10. Crash and fire facilities.
- 1.18. Commercial and General Aviation
- 2. Agriculture
- 3. Astronomy and Astrophysics
- 4. Atmospheric Sciences
- 5. Behavioral and Social Sciences
- 6. Biological and Medical Sciences
- 7. Chemistry
- 8. Earth Sciences and Oceanography
- 9. Electrotechnology and Fluidics
- 10. Power Production and Energy Conversion (Nonpropulsive)
- 11. Materials
- 12. Mathematical and Computer Sciences
- 13. Mechanical, Industrial, Civil and Marine Engineering
- 14. Test Equipment, Research Facilities and Reprography
- 15. Military Sciences
- 16. Guided Missile Technology
- 17. Navigation, Detection and Countermeasures
- 18. Nuclear Science and Technology
- 19. Ordnance
- 20. Physics
- 21. Propulsion, Engines and Fuels
- 22. Space Technology
- 23. Biotechnology
- 24. Environmental Pollution and Control
- 25. Communications
  - 25.1. Telemetry
    - 25.1.1. Transmitters,
    - 25.1.2. Receivers, and
    - 25.1.3. Antennas. Includes acoustic, optical, wired
  - 25.2. Radio Communications
    - 25.2.1. Communication by radio waves;
    - 25.2.2. Microwave communications;
    - 25.2.3. Television communications.
  - 25.3. Non-Radio Communications
  - 25.4. Voice Communications
    - 25.4.1. Research and development in vocal communication;
    - 25.4.2. Speech intelligibility;
    - 25.4.3. Speech recognition;
    - 25.4.4. Speech analysis and synthesis.
  - 25.5. Command, Control and Communications Systems

Defense Technical Information Center (2000). *Subject categorization guide for defense science & technology*. Ft. Belvoir, VA: Author. Retrieved June 12, 2001, from the World Wide Web: <http://www.dtic.mil/dtic/subcatguide/>



## Appendix B-2.

### TII Technology Classification Codes.

1. Biology, Biotechnology
  - 1.1 Agriculture
  - 1.2 Bioengineering
  - 1.3 Biology
  - 1.4 Fishing Technology
  - 1.5 Health Technology
2. Energy Technologies
  - 2.1 Combustion and Ignition
  - 2.2 Electricity Generation
  - 2.3 Energy Conservation
  - 2.4 Energy Saving
  - 2.5 Energy Storage
  - 2.6 Oil and Gas Exploration Technology
  - 2.7 Renewable Energy Technologies
3. Environmental Technologies
  - 3.1 Biogeochemical Engineering
  - 3.2 Clean Technologies
  - 3.3 Environmental Monitoring
  - 3.4 Marine Technologies
  - 3.5 Pollution Control
  - 3.6 Water Treatment
  - 3.7 Protection Technologies
  - 3.8 Waste Management/Treatment
4. Information Technologies,
  - 4.1 Telecommunications
  - 4.2 CAD/CAE/CAM/CIM Technologies
  - 4.3 Coding/Decoding Technologies
  - 4.4 Computer Hardware
  - 4.5 Computer Software
  - 4.6 Computer Training Services
  - 4.7 Office Automation Technologies
  - 4.8 Telecommunications
5. Basic Industrial Technologies
  - 5.1 Assembly
  - 5.2 Blending/Mixing Technology
  - 5.3 Cleaning Technology
  - 5.4 Electronics
  - 5.5 Hydraulics and Pneumatics
  - 5.6 Industrial Logistics
  - 5.7 Measurement and Control
  - 5.8 Mining
  - 5.9 Optics
  - 5.10 Plasma Technology
6. Sectoral Industrial Technologies
  - 6.1 Chemical Engineering and Production
  - 6.2 Construction/Building Technology
  - 6.3 Electrical Engineering and Production
  - 6.4 Food Processing
  - 6.5 Games, Sport and Leisure
  - 6.6 Industrial Engineering and Production
  - 6.7 Mechanical Engineering and Production
  - 6.8 Printing/Publishing
  - 6.9 Textiles
  - 6.10 Transport
7. Materials Production and Processing
  - 7.1 Basic Materials
  - 7.2 Advanced Materials
  - 7.3 Metallurgy

TII (2000). *Technology classification codes*. Luxembourg: Author. Retrieved November 25, 2001, from the World Wide Web: <http://62.218.58.195/tii/secret/trn/tcc1.htm>

### **Appendix B-3.**

#### **Library of Congress Classification Outline for Technology.** (subclass TL expanded)

##### **Class T—Technology**

- Subclass T Technology (general)
- Subclass TA Engineering (general). Civil engineering
- Subclass TC Hydraulic engineering—Ocean engineering
- Subclass TD Environmental technology. Sanitary engineering
- Subclass TE Highway engineering. Roads and pavement
- Subclass TF Railroad engineering and operation
- Subclass TG Bridge engineering
- Subclass TH Building construction
- Subclass TJ Mechanical engineering and machinery
- Subclass TK Electrical engineering. Electronics. Nuclear engineering
- Subclass TL Motor vehicles. Aeronautics. Astronautics
  - TL1-484 Motor vehicles. Cycles
  - TL500-777 Aeronautics. Aeronautical engineering
  - TL780-785.8 Rocket propulsion. Rockets
  - TL787-4050 Astronautics. Space travel
- Subclass TN Mining engineering. Metallurgy
- Subclass TP Chemical technology
- Subclass TR Photography
- Subclass TS Manufactures
- Subclass TT Handicrafts, Arts and crafts
- Subclass TX Home economics

## Appendix B-4.

### Blanchard's Taxonomy of Displays.

1. Visual displays
  - 1.1. Indicator lights (transilluminated)
    - 1.1.1. Single status
    - 1.1.2. Multiple status
    - 1.1.3. Lighted pushbutton displays
  - 1.2. Sequential access digital readout
    - 1.2.1. Electromechanical drum counters
    - 1.2.2. Flag counters
  - 1.3. Random-access digital readouts
    - 1.3.1. Segmented matrices
    - 1.3.2. Cold cathode tubes
    - 1.3.3. Edge-lighted plates
    - 1.3.4. Projection readouts
    - 1.3.5. Back-lighted belt displays
    - 1.3.6. Light-emitting diode displays
  - 1.4. Scalar displays
    - 1.4.1. Moving pointer, fixed scale
    - 1.4.2. Fixed pointer, moving scale
  - 1.5. CRT spatial relation displays
    - 1.5.1. Radar displays
    - 1.5.2. Sonar displays
  - 1.6. CRT alphanumeric-pictorial displays
    - 1.6.1. Computer output displays
    - 1.6.2. Television output displays
    - 1.6.3. Infrared sensor displays
    - 1.6.4. Low-light-level TV displays
  - 1.7. CRT electronic parameter displays
    - 1.7.1. Waveform displays
    - 1.7.2. Bargraph displays
    - 1.7.3. Analog computer output displays
  - 1.8. Status displays
    - 1.8.1. Plot board
    - 1.8.2. Map displays
    - 1.8.3. Projected displays
    - 1.8.4. Matrix boards
    - 1.8.5. Large screen displays
  - 1.9. Hard copy readout displays
    - 1.9.1. Printers
    - 1.9.2. Recorders
    - 1.9.3. Plotters
2. Auditory displays
  - 2.1. Electromechanical
    - 2.1.1. Bells
    - 2.1.2. Buzzers
    - 2.1.3. Horns
    - 2.1.4. Sirens
  - 2.2. Electronic
    - 2.2.1. Electronic tones and signals
    - 2.2.2. Recorded signals directions

Blanchard, R. E. (1973). *Requirements, concept, and specification for a navy human factors performance data store* [Report no. 102-2] (pp. 89-90). Santa Monica, CA: Behaviormetrics. Cited in Gawron, V. J., Drury, C. G., Czaja, S. J., & Wilkins, D. M. (1989). A taxonomy of independent variables affecting human performance. *International Journal of Man-Machine Studies*, 31, 643-672.

## **Appendix B-5.**

### **Human Factors Checklist for the Design and Evaluation of Air Traffic Control Systems.**

1. General
2. Visual displays
3. Auditory displays
4. Cognitive workload
5. Data entry procedures
6. Data entry and control devices
7. Ergonomics and workstation design
8. Human factors planning and evaluation

Cardosi, K. M., & Murphy, E. D. (Eds.) (1995). *Human factors checklist for the design and evaluation of air traffic control systems*. Final Report [DOT/FAA/RD-95/3.1]. Washington, DC: Federal Aviation Administration.

## Appendix B-6.

### Willis Input-Output Hierarchical Model.

1. Receptor activity (input)
  - 1.1. Discrimination—nonverbal cues (data storage)
    - 1.1.2. Detection—nonverbal cues
    - 1.1.3. Identification, recognition (nonverbal cues)
  - 1.2. Discrimination—verbal cues (data storage)
    - 1.2.2. Detection—verbal cues
    - 1.2.3. Identification, recognition (verbal cues)
2. CNS activity (black box)
  - 2.1. Recall (data retrieval)
    - 2.1.2. Recalling facts
    - 2.1.3. Recalling principles
    - 2.1.4. Recalling procedures
  - 2.2. Symbolic data operations (data manipulation or processing)
    - 2.2.2. Using principles, interpreting, inferring
    - 2.2.3. Making decisions with known and given alternatives
    - 2.2.4. Making decisions with unspecified alternatives
    - 2.2.5. Making decisions with unknown alternatives
3. Effector activity (output)
  - 3.1. Skilled motor acts (data output)
    - 3.1.2. Positioning movement
    - 3.1.3. Repetition movement
    - 3.1.4. Continuous movement
    - 3.1.5. Serial movement
    - 3.1.6. Static reaction
  - 3.2. Overt verbalization
    - 3.2.2. Oral verbalization
    - 3.2.3. Written verbalization
    - 3.2.4. Other overt verbalization

Willis, M. P. (1961). *Deriving training device implications from learning theory principles* (NAVTRADEVCEEN 784-1). Port Washington, NY: USNTDC. Cited in Fleishman, E. A., & Quaintance, M. K. (1984). *Taxonomies of human performance: The description of human tasks* (pp. 97-98). Orlando, FL: Academic Press.

## Appendix B-7.

### Berliner Classificatory Scheme.

1. Perceptual processes
  - 1.1 Searching and receiving information
    - 1.1.1. Detects
    - 1.1.2. Inspects
    - 1.1.3. Observes
    - 1.1.4. Reads
    - 1.1.5. Receives
    - 1.1.6. Scans
    - 1.1.7. Surveys
  - 1.2. Identifying objects, actions, events
    - 1.2.1. Discriminates
    - 1.2.2. Identifies
    - 1.2.3. Locates
2. Mediational processes
  - 2.1. Information processing
    - 2.1.1. Categorizes
    - 2.1.2. Calculates
    - 2.1.3. Codes
    - 2.1.4. Computes
    - 2.1.5. Interpolates
    - 2.1.6. Itemizes
    - 2.1.7. Tabulates
    - 2.1.8. Translates
  - 2.2. Problem-solving and decision-making
    - 2.2.1. Compares
    - 2.2.2. Computes
    - 2.2.3. Estimates
    - 2.2.4. Plans
3. Communication processes
  - 3.1. Advises
  - 3.2. Answers
  - 3.3. Communicates
  - 3.4. Directs
  - 3.5. Indicates
  - 3.6. Informs
  - 3.7. Instructs
  - 3.8. Requests
  - 3.9. Transmits
4. Motor processes
  - 4.1. Complex—continuous
    - 4.1.1. Adjusts
    - 4.1.2. Aligns
    - 4.1.3. Regulates
    - 4.1.4. Synchronizes
    - 4.1.5. Tracks
  - 4.2. Simple—discrete
    - 4.2.1. Activates
    - 4.2.2. Closes
    - 4.2.3. Connects
    - 4.2.4. Disconnects
    - 4.2.5. Joins
    - 4.2.6. Moves
    - 4.2.7. Presses
    - 4.2.8. Sets

Berliner, D. C., Angell, D., & Shearer, J.W. (1964). *Behaviors, measures, and instruments for performance evaluation in simulated environments*. Paper presented at a symposium and workshop on the quantification of human performance, Albuquerque, NM, August 1964. Cited in Fleishman, E. A., & Quaintance, M. K. (1984). *Taxonomies of human performance: The description of human tasks* (pp. 93-95). Orlando, FL: Academic Press.

## **Appendix B-8.**

### **Fitts' Taxonomy.**

1. Receptor
2. Central Nervous System
3. Effector
4. Environment
5. Control
6. Machine
7. Display

Fitts, P. M. (1965). Factors in complex skill training. In R. Glaser (Ed.), *Training research and education*. New York: Wiley.

## Appendix B-9.

### Meister's Taxonomy.

- |        |  |        |                          |
|--------|--|--------|--------------------------|
| 1.     | Functions: subsystem management        | 4.1.3. | Auditory                 |
| 2.     | Tasks: tracking                        | 4.1.4. | Kinesthetic              |
| 2.1.   | Visual tracking only                   | 4.2.   | Mechanism                |
| 2.2.   | Visual tracking plus position plotting | 4.2.2. | Directly viewed event    |
| 3.     | Behavioral elements: motor responses   | 4.2.3. | Display                  |
| 3.1.   | Depress single control                 | 4.2.4. | Written material         |
| 3.2.   | Turn single rotary control             | 4.3.   | Characteristics          |
| 3.3.   | Adjust control to specified value      | 4.3.2. | Alphanumerics            |
| 3.4.   | Activate bank of controls              | 4.3.3. | Raw stimuli              |
| 3.5.   | Type message on keyboard               | 4.3.4. | Coded stimuli            |
| 3.6.   | Insert object                          | 4.3.5. | Changing/moving stimulus |
| 3.7.   | Remove object                          | 4.3.6. | Static stimulus          |
| 3.8.   | Lift object                            | 4.3.7. | Multiple characteristics |
| 3.9.   | Move object                            | 4.4.   | Information presented    |
| 3.10.  | Place object                           | 4.4.2. | Quantitative             |
| 3.11.  | Open or close door                     | 4.4.3. | Qualitative              |
| 3.12.  | Connect or disconnect                  | 4.4.4. | Content                  |
| 3.13.  | Write                                  | 4.5.   | Duration                 |
| 4.     | Initiating stimulus                    | 4.5.2. | Persistent               |
| 4.1.   | Type                                   | 4.5.3. | Short-lived              |
| 4.1.2. | Visual\                                | 4.6.   | Number                   |
|        |  | 4.6.2. | Single                   |
|        |  | 4.6.3. | Multiple                 |

From Finley, D. L., Obermayer, R. W., Bertone, C. M., Meister, D., & Muckler, F. A. (1970). *Human performance prediction in man-machine systems: A technical review*. [Vol. 1, NASA CR-1614]. Canoga Park, CA: The Bunker-Ramo Corporation. Cited in Fleishman, E. A., & Quaintance, M. K. (1984). *Taxonomies of human performance: The description of human tasks*. Orlando, FL: Academic Press



## Appendix B-10.

### Farina and Wheaton's Task Characteristics Taxonomy.

1. Task
  - 1.1. Goal
    - 1.1.1. Number of output units
    - 1.1.2. Duration for which an output unit is maintained
    - 1.1.3. Number of elements per output unit
    - 1.1.4. Workload imposed by task goal
    - 1.1.5. Difficulty of goal attainment
  - 1.2. Responses
    - 1.2.1. Precision
    - 1.2.2. Rate
    - 1.2.3. Simultaneity
    - 1.2.4. Amount of muscular effort
  - 1.3. Procedures
    - 1.3.1. Number of steps
    - 1.3.2. Dependency among procedural steps
    - 1.3.3. Adherence to procedures
    - 1.3.4. Procedural complexity
  - 1.4. Stimuli
    - 1.4.1. Variability
    - 1.4.2. Duration
    - 1.4.3. Regularity of occurrence
  - 1.5. Stimulus-response relationship
    - 1.5.1. Degree of operator control
    - 1.5.2. Reaction time/feedback lag relationship
    - 1.5.3. Decision-making

Farina, A. J., & Wheaton, G. R. (1971). *Development of a taxonomy of human performance: The task characteristic approach to performance prediction*. Technical Report AIR-726-2/71-TR-7. Washington, DC: American Institutes for Research. Cited in Fleishman, E. A., & Quaintance, M. K. (1984). *Taxonomies of human performance: The description of human tasks* (pp. 358-359). Orlando, FL: Academic Press.

## **Appendix B-11.**

### **Shingledecker, Crabtree and Acton's Taxonomy.**

1. Perceptual-input tasks
  - 1.1. Visual probability monitoring
  - 1.2. Visual target search
  - 1.3. Auditory monitoring
2. Central-processing tasks
  - 2.1. Memory
    - 2.1.1. Memory update
    - 2.1.2. Continuous recall
  - 2.2. Decision
    - 2.2.1. Spatial-pattern identification
    - 2.2.2. Linguistic processing
    - 2.2.3. Mental math
    - 2.2.4. Grammatical/analogical reasoning
    - 2.2.5. Flight decision assessment
    - 2.2.6. Supervisory control
3. Motor output tasks
  - 3.1. Subcritical instability tracking

Shingledecker, C. A., Crabtree, M. S., & Acton, W. H. (1982). Standardized tests for the evaluation and classification of workload metrics. *Proceedings of the Human Factors Society 26th Annual Meeting* (pp. 648-651). Santa Monica, CA: Human Factors Society.

## Appendix B-12.

### Carter's Taxonomy.

1. Data functions
  - 1.1. Add to/add an object
    - 1.1.1. Create object
      - 1.1.1.1. Create field
      - 1.1.1.2. Create record
      - 1.1.1.3. Create file
      - 1.1.1.4. Create directory
      - 1.1.1.5. Create a form
      - 1.1.1.6. Open window
    - 1.1.2. Define object's format
      - 1.1.2.1. Define field format
      - 1.1.2.2. Define record format
      - 1.1.2.3. Define file format
      - 1.1.2.4. Define form format
    - 1.1.3. Add data to object
      - 1.1.3.1. Add data to record or file
      - 1.1.3.2. Append file to file
      - 1.1.3.3. Link file to directory
      - 1.1.3.4. Join (append) directories
      - 1.1.3.5. Add protection to an object
        - 1.1.3.5.1. Protect an object
        - 1.1.3.5.2. Assign a password
        - 1.1.3.5.3. Grant access
    - 1.1.4. Copy object
      - 1.1.4.1. Copy field
      - 1.1.4.2. Copy record
      - 1.1.4.3. Copy file
      - 1.1.4.4. Copy window
  - 1.2. Change object
    - 1.2.1. Change field
      - 1.2.1.1. Move field
    - 1.2.2. Change record
      - 1.2.2.1. Move record
    - 1.2.3. Change file
      - 1.2.3.1. Split file
      - 1.2.3.2. Sort file
      - 1.2.3.3. Translate characters
      - 1.2.3.4. Encrypt/decrypt a file
      - 1.2.3.5. Encrypt a file
      - 1.2.3.6. Decrypt a file
      - 1.2.3.7. Update one file to another
    - 1.2.4. Change object name
      - 1.2.4.1. Change field name
      - 1.2.4.2. Change file/form name
    - 1.2.5. Change object form
      - 1.2.5.1. Change field format
      - 1.2.5.2. Change record format
      - 1.2.5.3. Change file format
      - 1.2.5.4. Change form format
    - 1.2.6. Change window
      - 1.2.6.1. Modify window
      - 1.2.6.2. Link windows
    - 1.2.7. Change protection
      - 1.2.7.1. Change password
      - 1.2.7.2. Change access
  - 1.3. Delete/delete from an object
    - 1.3.1. Delete an object
      - 1.3.1.1. Delete field
      - 1.3.1.2. Delete record
      - 1.3.1.3. Delete file
      - 1.3.1.4. Remove directory
      - 1.3.1.5. Delete form
      - 1.3.1.6. Close window
      - 1.3.1.7. Delete an index
    - 1.3.2. Remove from an object
      - 1.3.2.1. Empty or remove an object
        - 1.3.2.1.1. Empty a field
        - 1.3.2.1.2. Empty a record
        - 1.3.2.1.3. Empty a file
        - 1.3.2.1.4. Remove trailing blanks
        - 1.3.2.1.5. Remove link to directory
      - 1.3.2.2. Compact a file
      - 1.3.2.3. Remove protection
        - 1.3.2.3.1. Unprotect an object
        - 1.3.2.3.2. Remove password
        - 1.3.2.3.3. Remove access
  - 1.4. Get an object function

- 1.4.1. Find an object
  - 1.4.1.1. Find field, record, or file
    - 1.4.1.1.1. Find field
    - 1.4.1.1.2. Find record
    - 1.4.1.1.3. Find file
  - 1.4.1.2. Find protection status/level
    - 1.4.1.2.1. Find protection status
    - 1.4.1.2.2. Find access
  - 1.4.1.3. Count words
  - 1.4.1.4. Compute two or more fields
  - 1.4.1.5. Find object type
- 1.4.2. List all objects
  - 1.4.2.1. List all field names
  - 1.4.2.2. List all files or directories
  - 1.4.2.3. List all file names
  - 1.4.2.4. List all directories
  - 1.4.2.5. List all access permissions
- 1.4.3. Output an object function
  - 1.4.3.1. Output a field
  - 1.4.3.2. Output a file or record
    - 1.4.3.2.1. Output a record
    - 1.4.3.2.2. Output a file
  - 1.4.3.3. Output a directory
- 1.4.4. Specify an object
  - 1.4.4.1. Select a file
  - 1.4.4.2. Activate a directory
  - 1.4.4.3. Designate ad index key field
- 1.5. Compare an object function
  - 1.5.1. Compare fields or records
    - 1.5.1.1. Compare fields
    - 1.5.1.2. Compare records
  - 1.5.2. Compare files
  - 1.5.3. Compare directories
- 2. Task execution function
  - 2.1. Signing on
  - 2.2. Signing off
  - 2.3. Change sign on password
  - 2.4. Starting execution function
    - 2.4.1. Execute now
    - 2.4.2. Execute in the future
    - 2.4.3. Execute again
    - 2.4.4. Execute batch
- 2.5. Stopping execution function
  - 2.5.1. Leave interactive program normally
  - 2.5.2. Terminate abnormally
  - 2.5.3. Interrupt processing
  - 2.5.4. Continue processing
  - 2.5.5. Stop batch requests before they start
  - 2.5.6. Undo previous processing
- 2.6. Execute status function
  - 2.6.1. Obtain status of current processes
  - 2.6.2. Obtain status of batch requests
- 2.7. Priority for execution function
  - 2.7.1. Change priority
  - 2.7.2. Obtain queue information
- 3. Information function
  - 3.1. User assistance function
    - 3.1.1. Assistance with commands
      - 3.1.1.1. List commands
      - 3.1.1.2. Explain command description
    - 3.1.2. Assistance with errors
      - 3.1.2.1. List errors
      - 3.1.2.2. Explain error type
    - 3.1.3. Provide tutorial
    - 3.1.4. Provided help screens
      - 3.1.4.1. Display next help screen
      - 3.1.4.2. Display previous help screen
      - 3.1.4.3. Return from help
    - 3.1.5. Provide keyboard assistance
  - 3.2. Provide other information function
    - 3.2.1. Provide information on system users
    - 3.2.2. Provide information on last sign on of users
    - 3.2.3. Provide information on where use is
    - 3.2.4. Provide information on last commands executed
- 4. Peripheral function
  - 4.1. Terminal functions
  - 4.2. Disk functions

- 4.3. Other peripheral control functions
- 5. Special function
  - 5.1. User to user communications functions
  - 5.2. Date and time functions
  - 5.3. Writing aids
  - 5.4. Arithmetic operations
  - 5.5. System utilization accounting
- 6. Bibliographic functions
- 7. Spread sheet functions
- 8. Graphics
- 9. Text editing functions

Carter, J. A., Jr. (1986). A taxonomy of user-oriented functions. *International Journal of Man-Machine Studies*, 24, 286-270.

## **Appendix B-13.**

### **A Model of Human Information Processing.**

1. Senses
  - 1.1. Vision
    - 1.1.1. Contrast sensitivity
    - 1.1.2. Color vision
    - 1.1.3. Night vision
    - 1.1.4. Depth perception
  - 1.2. Hearing
  - 1.3. Olfactory
  - 1.4. Taste
  - 1.5. Tactile
  - 1.6. Haptic
  - 1.7. Proprioception
2. Perception
  - 2.1. Attention
    - 2.1.1. Focused attention
    - 2.1.2. Divided attention
  - 2.2. Long-Term Memory
    - 2.2.1. Event memory
      - 2.2.1.1. Episodic memory
      - 2.2.1.2. Prospective memory
    - 2.2.2. Semantic memory
      - 2.2.2.1. Declarative
      - 2.2.2.2. Procedural
3. Decision-making and response selection
  - 3.1. Attention
    - 3.1.1. Focused attention
    - 3.1.2. Divided attention
  - 3.2. Long-Term Memory
    - 3.2.1. Event memory
      - 3.2.1.1. Episodic memory
      - 3.2.1.2. Prospective memory
    - 3.2.2. Semantic memory
      - 3.2.2.1. Declarative
      - 3.2.2.2. Procedural
  - 3.3. Working Memory
    - 3.3.1. Cue reception and integration
    - 3.3.2. Hypothesis generation
    - 3.3.3. Hypothesis evaluation and selection
    - 3.3.4. Action generation and selection
4. Response execution
  - 4.1. Discrete control
    - 4.1.1. Verbal/symbolic input
    - 4.1.2. Voice input
  - 4.2. Continuous control

Wickens, C. D. (1992). *Engineering psychology and human performance* (2nd ed.). New York: HarperCollins.

Wickens, C. D., Gordon, S. G., & Liu, Y. (1998). *An introduction to human factors engineering*. New York: Addison Wesley Longman.

## **Appendix B-14.**

### **Miller's Taxonomy.**

1. Goal orientation and set
2. Reception of task information
  - 2.1. Search and scan
  - 2.2. Identification
  - 2.3. Noise filtering
3. Retention of task information
  - 3.1. Short-term retention
  - 3.2. Long-term retention
  - 3.3. Memory for codes
4. Interpretation and problem solving
5. Motor response mechanisms

Miller, R. B. (1962). Task Description and analysis. In R. M. Cagne (Ed.), *Psychological Principles in System Development* (ch. 6). New York: Holt, Rinehart, and Winston.

## **Appendix B-15.**

### **Meyer, Laveson, Pape and Edwards's Taxonomy.**

1. Mental action classification
  - 1.1 Information processing
    - 1.1.1 Determine
    - 1.1.2 Sustain
    - 1.1.3 Discern
  - 1.2 Decision processing
  - 1.3 Simple processing
2. Motor action classification

Meyer, R. P., Laveson, J. I., Pape, G. L. & Edwards, B. (1978). *Development and application of a task taxonomy for tactical flying. (AFHRL-TR-78-42)*. Brooks AFB, TX: Human Resources Laboratory.



## **Appendix B-16.**

### **Gagne's Taxonomy of CNS Processes.**

1. Intellectual skills
  - 1.1. Generate solution to a novel problem
  - 1.2. Apply rule to a specific example
  - 1.3. Classify an object/situation with a definition
  - 1.4. Identify a class of object characteristics, objects, or events
  - 1.5. Distinguish object features as same or different
2. Cognitive strategy
3. Verbal information
4. Attitude

Adapted from Gagne, R. M. (1974). *Essentials of learning for instruction*. New York: Holt, Rinehart, and Winston. Cited in Gawron, V. J., Drury, C. G., Czaja, S. J., & Wilkins, D. M. (1989). A taxonomy of independent variables affecting human performance. *International Journal of Man-Machine Studies*, 31, 643-672.

## **Appendix B-17.**

### **Harrow's Taxonomy of the Psychomotor Domain.**

1. Reflex movements
  - 1.1. Segmental reflexes
  - 1.2. Intersegmental reflexes
  - 1.3. Suprasegmental reflexes
2. Basic fundamental movements
  - 2.1. Locomotor movements
  - 2.2. Non-locomotor movements
  - 2.3. Manipulative movements
3. Perceptual abilities
  - 3.1. Kinesthetic discrimination
  - 3.2. Visual discrimination
  - 3.3. Auditory discrimination
  - 3.4. Tactile discrimination
  - 3.5. Coordinated abilities
4. Physical abilities
  - 4.1. Endurance
  - 4.2. Strength
  - 4.3. Flexibility
  - 4.4. Agility
5. Skilled movements
  - 5.1. Simple adaptive skill
  - 5.2. Compound adaptive skill
  - 5.3. Complex adaptive skill
6. Non-discursive communication
  - 6.1. Expressive movement
  - 6.2. Interpretive movement

Harrow, A. J. (1972). *A taxonomy of the psychomotor domain* (pp. 1-2). New York: Davis McKay Company.

## **Appendix B-18.**

### **Hindmarch's Taxonomy.**

1. Sensory
  - 1.1. Stimulus detection
  - 1.2. Perception
  - 1.3. Recognition
2. Central Nervous System
  - 2.1. Processing
  - 2.2. Integration
  - 2.3. Memory
  - 2.4. Learning
3. Motor
  - 3.1. Ballistic
  - 3.2. Gross
  - 3.3. Fine
  - 3.4. Coordination

Hindmarch, I. (1980). Psychomotor function and psychoactive drugs. *Journal of Clinical Pharmacology*, 10, 189-209.

## **Appendix B-19.**

### **Types of Human Interaction With Automation.**

1. Information acquisition
2. Information analysis
3. Decision selection
4. Action implementation

Parasuraman, R., Sheridan, T. B., & Wickens, C. D. (2000). A model for types and levels of human interaction with automation. *IEEE Transactions on Systems, Man, and Cybernetics*, A30(3), 286-295.

## Appendix B-20.

### Levine and Teichner's Information-Theoretic Task Classification Approach.

1. Nature of constraint
  - 1.1. Internal
  - 1.2. External
2. Location of constraint
  - 2.1. Input
  - 2.2. Output
3. Redundancy
  - 3.1. Enhancement of task performance
  - 3.2. No effect on task performance
  - 3.3. Degradation of task performance
4. Input-output relation
  - 4.1. Input < output
  - 4.2. Input = output
  - 4.3. Input > output

Levine, J. M., & Teichner, W. H. (1971). *Development of a taxonomy of human performance: An information theoretic approach*. Technical Report AIR-726-2/71-TR-9. Washington, DC: American Institute for Research. Cited in Fleishman, E. A., & Quaintance, M. K. (1984). *Taxonomies of human performance: The description of human tasks*. Orlando, FL: Academic Press.

## **Appendix B-21.**

### **Chambers' Taxonomy of the Environment.**

1. Environment
  - 1.1. Physical
    - 1.1.1. Pressure
    - 1.1.2. Thermal
    - 1.1.3. Contaminants/toxicants
    - 1.1.4. Radiation
    - 1.1.5. Acceleration
    - 1.1.6. Reduced/zero gravity
    - 1.1.7. Vibration
    - 1.1.8. Noise
      - 1.1.8.2. Medium
        - 1.1.8.2.1. Atmosphere
        - 1.1.8.2.2. Hydrosphere
        - 1.1.8.2.3. Communication
      - 1.1.8.3. Range
        - 1.1.8.3.1. Infrasonic
        - 1.1.8.3.2. Sonic
        - 1.1.8.3.3. Ultrasonic
      - 1.1.8.4. Frequency
        - 1.1.8.4.1. Constant
        - 1.1.8.4.2. Variable
      - 1.1.8.5. Intensity
        - 1.1.8.5.1. Constant
        - 1.1.8.5.2. Variable
      - 1.1.8.6. Duration
        - 1.1.8.6.1. Single
        - 1.1.8.6.2. Continuous
        - 1.1.8.6.3. Intermittent
        - 1.1.8.6.4. Impulsive
      - 1.1.8.7. Spectrum
        - 1.1.8.7.1. Pure
        - 1.1.8.7.2. Narrow band
        - 1.1.8.7.3. Broad band
    - 1.1.9. Terrain
    - 1.1.10. Electricity
    - 1.1.11. Magnetism
    - 1.1.12. Confinement
    - 1.1.13. Isolation
    - 1.1.14. Day/night cycles
    - 1.1.15. Drugs

Chambers, A. N. (1969). *Development of a taxonomy of human performance: a heuristic model for the development of classification systems*. Technical Report of American Institutes for Research in Behavioral Sciences, 04. Washington, DC: American Institutes for Research.

## Appendix B-22.

### Variables Affecting Human Performance.

1. Independent variables
  - 1.1. Task Requirements/Conditions
    - 1.1.1. Operations
      - 1.1.1.1. Directions
        - 1.1.1.1.1. Objectives/Purposes
        - 1.1.1.1.2. Goals
        - 1.1.1.1.3. Criteria
      - 1.1.1.2. Equipment/Materials
        - 1.1.1.2.1. Operative
        - 1.1.1.2.2. Protective
        - 1.1.1.2.3. Maintenance
        - 1.1.1.2.4. Support
        - 1.1.1.2.5. Facilities
        - 1.1.1.2.6. Training
        - 1.1.1.2.7. Materials
    - 1.1.3. Personnel
      - 1.1.3.1. Communication
      - 1.1.3.2. Linguistics
    - 1.1.4. Environment
      - 1.1.4.1. Physical
      - 1.1.4.2. Social
  - 1.2. Subject variables
    - 1.2.1. Selection
      - 1.2.1.1. Physical
      - 1.2.1.2. Medical
      - 1.2.1.3. Educational
      - 1.2.1.4. Experience
    - 1.2.2. Training/Conditioning
      - 1.2.2.1. Instructions
      - 1.2.2.2. Practice conditions
      - 1.2.2.3. Evaluation
      - 1.2.2.4. Physical conditioning
2. Intervening variables
  - 2.1. Human functions/capabilities
    - 2.1.1. Sensing
    - 2.1.2. Perceiving
    - 2.1.3. Cognition
    - 2.1.4. Motor
3. Mediating/moderating variables
  - 3.1. Psychological
    - 3.1.1. Attention
    - 3.1.2. Learning
    - 3.1.3. Motivation
    - 3.1.4. Personality
  - 3.2. Physiological
    - 3.2.1. Cardiopulmonary
    - 3.2.2. Thermal regulation
    - 3.2.3. Etc.
  - 3.3. Anthropometric/Biomechanical
    - 3.3.1. Dimensions
    - 3.3.2. Strength, endurance
    - 3.3.3. Etc.
4. Dependent variables
  - 4.1. Responses
    - 4.1.1. Physical
    - 4.1.2. Physiological
    - 4.1.3. Psychological
      - 4.1.3.1. Objective (performance)
      - 4.1.3.2. Subjective
  - 4.2. Pathological

Chambers, A. N. (1969). *Development of a taxonomy of human performance: A heuristic model for the development of classification systems*. [Technical Report No. 4]. Washington, DC: American Institutes for Research.



## **Appendix B-23.**

### **Human's Taxonomy.**

#### **1. Environment**

##### **1.1.Type**

- 1.1.1. Laboratory
- 1.1.2. Office
- 1.1.3. Outer space

##### **1.2.Attributes**

- 1.2.1. Acceleration
- 1.2.2. Confinement
- 1.2.3. Contaminants/toxicants
- 1.2.4. Day/night cycles
- 1.2.5. Electricity
- 1.2.6. Isolation
- 1.2.7. Lighting
  - 1.2.7.1.Type
    - 1.2.7.1.1. Fluorescent
    - 1.2.7.1.2. Incandescent
    - 1.2.7.1.3. Sunlight
  - 1.2.7.2.Attributes
    - 1.2.7.2.1. Luminance in foot lamberts
- 1.2.8. Magnetism
- 1.2.9. Noise
  - 1.2.9.1.Duration
    - 1.2.9.1.1. Continuous
    - 1.2.9.1.2. Impulsive
    - 1.2.9.1.3. Intermittent
    - 1.2.9.1.4. Single
  - 1.2.9.2.Frequency
    - 1.2.9.2.1. Constant
    - 1.2.9.2.2. Variable
  - 1.2.9.3.Intensity
    - 1.2.9.3.1. Constant
    - 1.2.9.3.2. Variable
  - 1.2.9.4.Medium
    - 1.2.9.4.1. Atmosphere
    - 1.2.9.4.2. Communication
    - 1.2.9.4.3. Hydrosphere
  - 1.2.9.5.Range
    - 1.2.9.5.1. Infrasonic
    - 1.2.9.5.2. Sonic
    - 1.2.9.5.3. Ultrasonic
  - 1.2.9.6.Spectrum

- 1.2.9.6.1. Broad band
  - 1.2.9.6.2. Narrow band
  - 1.2.9.6.3. Pure
- 1.2.10. Pressure
  - 1.2.10.1. Ambient vapor pressure in MB
  - 1.2.10.2. Gravity
- 1.2.11. Radiation
  - 1.2.11.1. Infrared
  - 1.2.11.2. Microwave
  - 1.2.11.3. Radio frequency
  - 1.2.11.4. Ultraviolet
  - 1.2.11.5. Visible
  - 1.2.11.6. X-Ray
- 1.2.12. Reduced/zero gravity
- 1.2.13. Terrain
- 1.2.14. Thermal
  - 1.2.14.1. Ambient dry bulb temperature in degrees Celsius
  - 1.2.14.2. Humidity
- 1.2.15. Vibration
- 2. Subject
  - 2.1. Physical characteristics
    - 2.1.1. Age
    - 2.1.2. Effector
      - 2.1.2.1. Feet
        - 2.1.2.1.1. Agility
        - 2.1.2.1.2. Dominance
        - 2.1.2.1.3. Lift strength
      - 2.1.2.2. Hands
        - 2.1.2.2.1. Dominance
        - 2.1.2.2.2. Flexibility
        - 2.1.2.2.1. Grip strength
      - 2.1.2.3. Voice
    - 2.1.3. Fatigue
    - 2.1.4. Gender
      - 2.1.4.1. Female
      - 2.1.4.2. Male
    - 2.1.5. Height in cm
    - 2.1.6. Limbs
      - 2.1.6.1. Legs
        - 2.1.6.1.1. Endurance
        - 2.1.6.1.2. Strength
      - 2.1.6.2. Arms
        - 2.1.6.2.1. Length
    - 2.1.7. Weight in Kg
  - 2.2. Mental state
    - 2.1.1. Attention span

- 2.1.2. Drugs
  - 2.1.2.1.Type
  - 2.1.2.2.Attributes
    - 2.1.2.2.1. Dosage
    - 2.1.2.2.2. Number of days since last taken
    - 2.1.2.2.3. Number of days taken
- 2.1.3. Memory
  - 2.1.3.1.Long term
    - 2.1.3.1.1. Number of times has done task before
  - 2.1.3.2.Short term
    - 2.1.3.2.1. Number of items stored
- 2.1.4. Personality trait
  - 2.1.4.1.Perceived probability of success
- 2.1.5. Sleep in hours
- 2.1.6. Work schedule
  - 2.1.6.1.Days on duty
  - 2.1.6.2.Rest periods
    - 2.1.6.2.1. Duration
    - 2.1.6.2.2. Frequency
- 2.2. Senses
  - 2.2.1. Auditory
    - 2.2.1.1.Acuity
    - 2.2.1.2.Biaural
    - 2.2.1.3.Monaural
    - 2.2.1.4.Tone perception
  - 2.2.2. Olfactory
  - 2.2.3. Tactual
  - 2.2.4. Vision
    - 2.2.4.1.Accommodation
    - 2.2.4.2.Acuity
    - 2.2.4.3.Binocular
    - 2.2.4.4.Color perception
    - 2.2.4.5.Convergence
    - 2.2.4.6.Monocular
- 3. Task
  - 3.1. Control device
    - 3.1.1. Type
      - 3.1.1.1.Knob
      - 3.1.1.2.Lever
      - 3.1.1.3.Pedal
      - 3.1.1.4.Pushbutton
      - 3.1.1.5.Switch
        - 3.1.1.5.1. Rocker
        - 3.1.1.5.2. Rotary selector
        - 3.1.1.5.3. Toggle
      - 3.1.1.6.Track ball

- 3.1.1.7.Touch device
  - 3.1.1.7.1. Keyboard
    - 3.1.1.7.1.1.Membrane
    - 3.1.1.7.1.2.Teletype
  - 3.1.1.7.2. Light pen
  - 3.1.1.7.3. Pointer
  - 3.1.1.7.4. Touch panel
  - 3.1.1.7.5. Touch screen
- 3.1.1.8.Voice activated
- 3.1.1.9.Wheels
  - 3.1.1.9.1. Steering wheels
  - 3.1.1.9.2. Thumb wheels
- 3.1.2. Attributes
  - 3.1.2.1.Number of positions
  - 3.1.2.2.Size
  - 3.1.2.3.Type damping
  - 3.1.2.4.Type feedback
- 3.2. Display device
  - 3.2.1. Type
    - 3.2.1.1.Auditory displays
      - 3.2.1.1.1. Electromechanical
        - 3.2.1.1.1.1.Bells
        - 3.2.1.1.1.2.Buzzers
        - 3.2.1.1.1.3.Horns
        - 3.2.1.1.1.4.Sirens
      - 3.2.1.1.2. Electronic
        - 3.2.1.1.2.1.Electronic tones and signals
        - 3.2.1.1.2.2.Recorded signals directions
    - 3.2.1.2.Visual
      - 3.2.1.2.1. CRT alphanumeric-pictorial displays
        - 3.2.1.2.1.1.Computer output displays
        - 3.2.1.2.1.2.Infrared sensor displays
        - 3.2.1.2.1.3.Low-light-level TV displays
        - 3.2.1.2.1.4.Television output displays
      - 3.2.1.2.2. CRT electronic parameter displays
        - 3.2.1.2.2.1.Analog computer output displays
        - 3.2.1.2.2.2.Bargraph displays
        - 3.2.1.2.2.3.Waveform displays
      - 3.2.1.2.3. CRT spatial relation displays
        - 3.2.1.2.3.1.Radar displays
        - 3.2.1.2.3.2.Sonar displays
      - 3.2.1.2.4. Hard copy readout displays
        - 3.2.1.2.4.1.Plotters
        - 3.2.1.2.4.2.Printers
        - 3.2.1.2.4.3.Recorders
      - 3.2.1.2.5. Indicator lights (transilluminated)

- 3.2.1.2.5.1. Lighted pushbutton displays
    - 3.2.1.2.5.2. Multiple status
    - 3.2.1.2.5.3. Single status
  - 3.2.1.2.6. Light Emitting Diode (LED)
  - 3.2.1.2.7. Liquid Crystal Displays (LCD)
  - 3.2.1.2.8. Mechanical
  - 3.2.1.2.9. Projection
  - 3.2.1.2.10. Random-access digital readouts
    - 3.2.1.2.10.1. Back-lighted belt displays
    - 3.2.1.2.10.2. Cold cathode tubes
    - 3.2.1.2.10.3. Edge-lighted plates
    - 3.2.1.2.10.4. Light-Emitting Diode displays
    - 3.2.1.2.10.5. Projection readouts
    - 3.2.1.2.10.6. Segmented matrices
  - 3.2.1.2.11. Scalar displays
    - 3.2.1.2.11.1. Fixed pointer, moving scale
    - 3.2.1.2.11.2. Moving pointer, fixed scale
  - 3.2.1.2.12. Sequential-access digital readouts
    - 3.2.1.2.12.1. Electromechanical drum counters
    - 3.2.1.2.12.2. Flag counters
  - 3.2.1.2.13. Status displays
    - 3.2.1.2.13.1. Large screen displays
    - 3.2.1.2.13.2. Map displays
    - 3.2.1.2.13.3. Matrix boards
    - 3.2.1.2.13.4. Plot boards
    - 3.2.1.2.13.5. Projected displays
- 3.2.2. Attributes
  - 3.2.2.1. Size
    - 3.2.2.1.1. Diameter in cm
    - 3.2.2.1.2. Height in cm
    - 3.2.2.1.3. Width in cm
  - 3.2.2.2. Viewing conditions
    - 3.2.2.2.1. Collimation
    - 3.2.2.2.2. Distance of operator to display in cm
    - 3.2.2.2.3. Magnification
    - 3.2.2.2.4. Ocular design
      - 3.2.2.2.4.1. Binocular
      - 3.2.2.2.4.2. Dichoptic
      - 3.2.2.2.4.3. Monocular left eye
      - 3.2.2.2.4.4. Monocular right eye
    - 3.2.2.2.5. Resolution
    - 3.2.2.2.6. Visual angle/field of view in degrees
- 3.3. Machine
  - 3.3.1. Computer
    - 3.3.1.1. Mainframe
    - 3.3.1.2. Personal

- 3.3.2. Vehicles
  - 3.3.2.1. Aircraft
    - 3.3.2.1.1. Helicopter
    - 3.3.2.1.2. Jet
    - 3.3.2.1.3. Propeller
  - 3.3.2.2. Motorized ground vehicle
    - 3.3.2.2.1. Car
    - 3.3.2.2.2. Half track
    - 3.3.2.2.3. Jeep
    - 3.3.2.2.4. Tank
    - 3.3.2.2.5. Truck
  - 3.3.2.3. Ship
    - 3.3.2.3.1. Aircraft carrier
    - 3.3.2.3.2. Destroyer
    - 3.3.2.3.3. Submarine
  - 3.3.2.4. Spacecraft
- 3.3.3. Weapon
- 3.4. Stimulus
  - 3.4.1. Type
    - 3.4.1.1. Auditory
    - 3.4.1.2. Kinesthetic
    - 3.4.1.3. Visual
      - 3.4.1.3.1. Alphanumeric
      - 3.4.1.3.2. Graph
  - 3.4.2. Attributes
    - 3.4.2.1. Background
      - 3.4.2.1.1. Complexity
      - 3.4.2.1.2. Contrast
      - 3.4.2.1.3. Number of background characters
    - 3.4.2.2. Characteristics
      - 3.4.2.2.1. Alphanumerics
      - 3.4.2.2.2. Changing/moving stimulus
      - 3.4.2.2.3. Coded stimulus
      - 3.4.2.2.4. Conspicuity
      - 3.4.2.2.5. Raw stimulus
      - 3.4.2.2.6. Static stimulus
    - 3.4.2.3. Color
    - 3.4.2.4. Duration
      - 3.4.2.4.1. Continuous
      - 3.4.2.4.2. Intermittent
        - 3.4.2.4.2.1. Probability
        - 3.4.2.4.2.2. Rate
      - 3.4.2.4.3. Single
    - 3.4.2.5. Information presented
      - 3.4.2.5.1. Content
      - 3.4.2.5.2. Qualitative

- 3.4.2.5.3. Quantitative
  - 3.4.2.6.Location on display
    - 3.4.2.6.1. Center
    - 3.4.2.6.2. Lower left
    - 3.4.2.6.3. Lower middle
    - 3.4.2.6.4. Lower right
    - 3.4.2.6.5. Middle left
    - 3.4.2.6.6. Middle right
    - 3.4.2.6.7. Upper left
    - 3.4.2.6.8. Upper middle
    - 3.4.2.6.9. Upper right
    - 3.4.2.6.10. Predictability of location
  - 3.4.2.7.Mechanism
    - 3.4.2.7.1. Directly viewed event
    - 3.4.2.7.2. Display
    - 3.4.2.7.3. Written material
  - 3.4.2.8.Number
    - 3.4.2.8.1. Multiple
    - 3.4.2.8.2. Single
    - 3.4.2.8.3. Intermittent
  - 3.4.2.9.Range of values
  - 3.4.2.10. Relative movement
    - 3.4.2.10.1. Observer and target at rest
    - 3.4.2.10.2. Observer and target in motion
    - 3.4.2.10.3. Observer in motion, target at rest
    - 3.4.2.10.4. Observer at rest, target in motion
  - 3.4.2.11. Relative position of observer
    - 3.4.2.11.1. Horizontal range in Km
    - 3.4.2.11.2. Offset in Km
    - 3.4.2.11.3. Positions
      - 3.4.2.11.3.1. Air-to-air
      - 3.4.2.11.3.2. Air-to-ground
      - 3.4.2.11.3.3. At a display
      - 3.4.2.11.3.4. Ground-to-air
      - 3.4.2.11.3.5. Ground-to-ground
  - 3.4.2.12. Size/amplitude
    - 3.4.2.12.1. Signal-to-noise ratio
- 3.5. Task
  - 3.5.1. Type
    - 3.5.1.1.Communication
      - 3.5.1.1.1. Type
        - 3.5.1.1.1.1.Advise
        - 3.5.1.1.1.2.Answer
        - 3.5.1.1.1.3.Communicate
          - 3.5.1.1.1.3.1. Job-related
          - 3.5.1.1.1.3.2. Public-related

- 3.5.1.1.1.4. Comprehend
- 3.5.1.1.1.5. Coordinate
- 3.5.1.1.1.6. Direct
- 3.5.1.1.1.7. Indicate
- 3.5.1.1.1.8. Inform
- 3.5.1.1.1.9. Instruct
- 3.5.1.1.1.10. Request
- 3.5.1.1.1.11. Supervise
- 3.5.1.1.1.12. Transmit
- 3.5.1.1.2. Attributes
  - 3.5.1.1.2.1. Oral
  - 3.5.1.1.2.2. Written
- 3.5.1.2. Meditation
  - 3.5.1.2.1. Type
    - 3.5.1.2.1.1. Information processing
      - 3.5.1.2.1.1.1. Categorize
      - 3.5.1.2.1.1.2. Calculate
      - 3.5.1.2.1.1.3. Code
      - 3.5.1.2.1.1.4. Compute
      - 3.5.1.2.1.1.5. Interpolate
      - 3.5.1.2.1.1.6. Itemize
      - 3.5.1.2.1.1.7. Learn
      - 3.5.1.2.1.1.8. Tabulate
      - 3.5.1.2.1.1.9. Translate
    - 3.5.1.2.1.2. Problem solving and decision making
      - 3.5.1.2.1.2.1. Analyze
      - 3.5.1.2.1.2.2. Deduce
      - 3.5.1.2.1.2.3. Induce
      - 3.5.1.2.1.2.4. Calculate
      - 3.5.1.2.1.2.5. Choose
        - 3.5.1.2.1.2.5.1. Choose from known alternatives
        - 3.5.1.2.1.2.5.2. Choose from unknown alternatives
        - 3.5.1.2.1.2.5.3. Choose from unspecified alternatives
      - 3.5.1.2.1.2.6. Compare
        - 3.5.1.2.1.2.6.1. Order
      - 3.5.1.2.1.2.7. Compute
      - 3.5.1.2.1.2.8. Estimate
      - 3.5.1.2.1.2.9. Integrate
      - 3.5.1.2.1.2.10. Plan
      - 3.5.1.2.1.2.11. Supervise
    - 3.5.1.2.1.3. Recall
      - 3.5.1.2.1.3.1. Recall Facts
      - 3.5.1.2.1.3.2. Recall Principles
      - 3.5.1.2.1.3.3. Recall procedures
      - 3.5.1.2.1.3.4. Timeshare
  - 3.5.1.2.2. Attributes



- 3.5.1.2.2.1.Complexity
- 3.5.1.2.2.2.Difficulty.
- 3.5.1.3.Motor processes
  - 3.5.1.3.1. Type
    - 3.5.1.3.1.1.Complex-continuous
      - 3.5.1.3.1.1.1. Adjust
      - 3.5.1.3.1.1.2. Align
      - 3.5.1.3.1.1.3. Insert object
      - 3.5.1.3.1.1.4. Regulate
      - 3.5.1.3.1.1.5. Remove object
      - 3.5.1.3.1.1.6. Synchronize
      - 3.5.1.3.1.1.7. Track
        - 3.5.1.3.1.1.7.1.Visual tracking only
        - 3.5.1.3.1.1.7.2.Visual tracking plus position plotting
      - 3.5.1.3.1.1.8. Type message on keyboard
      - 3.5.1.3.1.1.9. Write
    - 3.5.1.3.1.2.Compound
    - 3.5.1.3.1.3.Reflex
      - 3.5.1.3.1.3.1. Intersegmental
      - 3.5.1.3.1.3.2. Segmental
      - 3.5.1.3.1.3.3. Suprasegmental
    - 3.5.1.3.1.4.Simple-discrete
      - 3.5.1.3.1.4.1. Activate
      - 3.5.1.3.1.4.2. Close
      - 3.5.1.3.1.4.3. Connect
      - 3.5.1.3.1.4.4. Disconnect
      - 3.5.1.3.1.4.5. Join
      - 3.5.1.3.1.4.6. Move
      - 3.5.1.3.1.4.7. Press
      - 3.5.1.3.1.4.8. Set
      - 3.5.1.3.1.4.9. Turn single rotary control
  - 3.5.1.3.2. Attributes
    - 3.5.1.3.2.1.Ballistic
    - 3.5.1.3.2.2.Continuous
    - 3.5.1.3.2.3.Coordinated
    - 3.5.1.3.2.4.Fine
    - 3.5.1.3.2.5.Gross
    - 3.5.1.3.2.6.Repetitive
    - 3.5.1.3.2.7.Serial
    - 3.5.1.3.2.8.Static
- 3.5.1.4.Perceptual processing
  - 3.5.1.4.1. Searching for and receiving information
    - 3.5.1.4.1.1.Detect
      - 3.5.1.4.1.1.1. Detect non-verbal cues
      - 3.5.1.4.1.1.2. Detect verbal cues
    - 3.5.1.4.1.2.Inspect

- 3.5.1.4.1.3.Observe
- 3.5.1.4.1.4.Read
- 3.5.1.4.1.5.Receive
- 3.5.1.4.1.6.Scan
- 3.5.1.4.1.7.Survey
- 3.5.1.4.2. Identifying objects, actions, events
  - 3.5.1.4.2.1.Discriminate
    - 3.5.1.4.2.1.1. Discriminate auditory cues
    - 3.5.1.4.2.1.2. Discriminate kinetic cues
    - 3.5.1.4.2.1.3. Discriminate non-verbal cues
    - 3.5.1.4.2.1.4. Discriminate tactile cues
    - 3.5.1.4.2.1.5. Discriminate verbal cues
    - 3.5.1.4.2.1.6. Discriminate visual cues
  - 3.5.1.4.2.2.Identify
    - 3.5.1.4.2.2.1. Identify non-verbal cues
    - 3.5.1.4.2.2.2. Identify verbal cues
  - 3.5.1.4.2.3.Recognize
    - 3.5.1.4.2.3.1. Recognize non-verbal cues
    - 3.5.1.4.2.3.2. Recognize verbal cues
- 3.5.2. Attributes
  - 3.5.2.1.Amount of labor required
  - 3.5.2.2.Complexity
  - 3.5.2.3.Degree of response chaining
  - 3.5.2.4.Difficulty
  - 3.5.2.5.Knowledge of results
  - 3.5.2.6.Output
  - 3.5.2.7.Pacing
  - 3.5.2.8.Precision
  - 3.5.2.9.Repetitiveness
  - 3.5.2.10. Skill demands
  - 3.5.2.11. Simultaneity of responses
  - 3.5.2.12. Task autonomy

## Appendix B-24.

### AIAA Human Factors Taxonomy.

- 1. Environment
  - 1.1. Natural environment
    - 1.1.1. Weather
      - 1.1.1.1. Air temperature
      - 1.1.1.2. Atmospheric pressure
      - 1.1.1.3. Winds
      - 1.1.1.4. Humidity
      - 1.1.1.5. Clouds
      - 1.1.1.6. Precipitation
      - 1.1.1.7. Electrical disturbances
      - 1.1.1.8. Visibility and natural light
    - 1.1.2. Terrain
      - 1.1.2.1. Topography
      - 1.1.2.2. Surface materials
      - 1.1.2.3.
  - 1.2. Artificial environment
    - 1.2.1. Nuclear (initial residual)
      - 1.2.1.1. Blast overpressure
      - 1.2.1.2. Radiation exposure
      - 1.2.1.3. Nuclear elements
    - 1.2.2. Chemical
      - 1.2.2.1. Contaminants/toxins
    - 1.2.3. Electromagnetic
      - 1.2.3.1. Electronic warfare
      - 1.2.3.2. Nuclear EMP
      - 1.2.3.3. Directed energy
    - 1.2.4. Constructed obstacles
    - 1.2.5. Obscurants and illumination
      - 1.2.5.1. Smoke
      - 1.2.5.2. Chaff
    - 1.2.6. Pressure
      - 1.2.6.1. Dynamic
      - 1.2.6.2. Static
    - 1.2.7. Kinetic projectiles
      - 1.2.7.1. Missiles
      - 1.2.7.2. Bombs
      - 1.2.7.3. Other delivery systems
    - 1.2.8. Acceleration
      - 1.2.8.1. Positive G
      - 1.2.8.2. Reduced/negative G
    - 1.2.9. Vibration
      - 1.2.9.1. Duration
      - 1.2.9.2. Frequency
      - 1.2.9.3. Intensity
    - 1.2.10. Man-made lighting
      - 1.2.10.1. Type
      - 1.2.10.2. Attributes
    - 1.2.11. Noise
      - 1.2.11.1. Duration
      - 1.2.11.2. Frequency
      - 1.2.11.3. Intensity
      - 1.2.11.4. Medium
      - 1.2.11.5. Range
    - 1.2.12. Altitude
      - 1.2.12.1. Reduced O<sub>2</sub>
      - 1.2.12.2. Partial pressure
  - 1.3. Operational environment
    - 1.3.1. Military mission constraints
    - 1.3.2. Enemy situation
    - 1.3.3. Friendly situation
    - 1.3.4. Level of activity
    - 1.3.5. Defense readiness condition
  - 1.4. Interior environment
    - 1.4.1. Facility description
    - 1.4.2. User activity support
    - 1.4.3. Surfaces
    - 1.4.4. Circulation
    - 1.4.5. Spatial configurations and arrangements
    - 1.4.6. Location
- 2. Human
  - 2.1. Physical characteristics
    - 2.1.1. Age
      - 2.1.1.1. Physiological responses
    - 2.1.2. Anthropometry
      - 2.1.2.1. Height
      - 2.1.2.2. Weight
      - 2.1.2.3. Physiology
      - 2.1.2.4. Feet
      - 2.1.2.5. Hands
      - 2.1.2.6. Voice

- 2.1.2.7.Legs
    - 2.1.2.8.arms
  - 2.1.3. Fatigability
    - 2.1.3.1.Physical neural impedance
    - 2.1.3.2.Mental
    - 2.1.3.3.Sleep deprivation
  - 2.1.4. Gender
    - 2.1.4.1.Male
    - 2.1.4.2.Female
- 2.2. Mental State
  - 2.2.1. Attention span
  - 2.2.2. Drugs
    - 2.2.2.1.Type
    - 2.2.2.2.Attribute
  - 2.2.3. Memory
    - 2.2.3.1.Long term
    - 2.2.3.2.Short term
  - 2.2.4. Personality traits
    - 2.2.4.1.Perceived probability of success
    - 2.2.4.2.Leadership trait
    - 2.2.4.3.Courage/cowardice
    - 2.2.4.4.Machoism
    - 2.2.4.5.Will to live
    - 2.2.4.6.Stubbornness
    - 2.2.4.7.Level of responsibility
  - 2.2.5. Work schedule
    - 2.2.5.1.Days on duty
    - 2.2.5.2.Mission duration
    - 2.2.5.3.Rest periods
    - 2.2.5.4.Rotation of task
  - 2.2.6. Experience
    - 2.2.6.1.Street smart
    - 2.2.6.2.New-guy factor
    - 2.2.6.3.Understanding of the task
    - 2.2.6.4.Birth order
    - 2.2.6.5.Combat experience
  - 2.2.7. Abilities
    - 2.2.7.1.Decision-making
    - 2.2.7.2.Detection
    - 2.2.7.3.Fine manipulation
    - 2.2.7.4.Gross manipulation
    - 2.2.7.5.Numeric manipulation
    - 2.2.7.6.Probability estimation
    - 2.2.7.7.Recognition
    - 2.2.7.8.Team coordination
    - 2.2.7.9.Time estimation
    - 2.2.7.10. Time sharing
    - 2.2.7.11. Tracking
    - 2.2.7.12. Communication
    - 2.2.7.13. Space estimation
- 2.2.8. Education
  - 2.2.8.1.Reading level
  - 2.2.8.2.ASVAT
  - 2.2.8.3.Learning
- 2.2.9. Intelligence
- 2.2.10. Emotions
  - 2.2.10.1. Fear
  - 2.2.10.2. Anger
  - 2.2.10.3. Frustration
  - 2.2.10.4. Hate
  - 2.2.10.5. Altruism
  - 2.2.10.6. Sadness/grief
  - 2.2.10.7. Anxiety
  - 2.2.10.8. Patriotism
  - 2.2.10.9. Willingness to fight
  - 2.2.10.10. Motivation
- 2.3. Senses
  - 2.3.1. Type
    - 2.3.1.1.Audition
    - 2.3.1.2.Olfaction
    - 2.3.1.3.Taction
    - 2.3.1.4.Vision
    - 2.3.1.5.Taste
    - 2.3.1.6.Vestibular
  - 2.3.2. Attributes
    - 2.3.2.1.Sensory parameters
    - 2.3.2.2.Sensory degradation
- 2.4. Health
  - 2.4.1. Injury
  - 2.4.2. Sickness
  - 2.4.3. Mental illness
  - 2.4.4. Nutrition
  - 2.4.5. Exercise
- 3. System
  - 3.1. Control Device
    - 3.1.1. Type
      - 3.1.1.1.Knob
      - 3.1.1.2.Lever
      - 3.1.1.3.Pedal
      - 3.1.1.4.Pushbutton

- 3.1.1.5.Switch
      - 3.1.1.6.Trackball
      - 3.1.1.7.Touch device
      - 3.1.1.8.Voice activated
      - 3.1.1.9.Wheel
    - 3.1.2. Attributes
      - 3.1.2.1.Number of positions
      - 3.1.2.2.Size
      - 3.1.2.3.Type of damping
      - 3.1.2.4.Type of feedback
  - 3.2. Display Device
    - 3.2.1. Type
      - 3.2.1.1.Auditory
      - 3.2.1.2.Visual
    - 3.2.2. Attributes
      - 3.2.2.1.Size
      - 3.2.2.2.Viewing condition
  - 3.3. Machine
    - 3.3.1. Computer
    - 3.3.2. Vehicle
    - 3.3.3. Weapon
  - 3.4. Stimulus
    - 3.4.1. Type
    - 3.4.2. Attributes
      - 3.4.2.1.Background
      - 3.4.2.2.Characteristics
      - 3.4.2.3.Duration
      - 3.4.2.4.Information presented
      - 3.4.2.5.Location of display
      - 3.4.2.6.Number
      - 3.4.2.7.Range of values
      - 3.4.2.8.Relative movement
      - 3.4.2.9.Relative position of observer
      - 3.4.2.10. Size/amplitude
      - 3.4.2.11. Discriminability
  - 3.5. Task Element
    - 3.5.1. Type
      - 3.5.1.1.Communication
      - 3.5.1.2.Mediation
      - 3.5.1.3.Motor processes
      - 3.5.1.4.Perceptual processing
    - 3.5.2. Attributes
      - 3.5.2.1.Amount of labor required
      - 3.5.2.2.Complexity
  - 3.5.2.3.Degree of response chaining
      - 3.5.2.4.Difficulty
      - 3.5.2.5.Knowledge of results
      - 3.5.2.6.Output
      - 3.5.2.7.Pacing
      - 3.5.2.8.Precision
      - 3.5.2.9.Repetitiveness
      - 3.5.2.10. Skill demands
      - 3.5.2.11. Simultaneity of responses
      - 3.5.2.12. Task autonomy
      - 3.5.2.13. Task allocation
      - 3.5.2.14. Payoff matrix
  - 3.6. Characteristics
    - 3.6.1. General system variables
    - 3.6.2. General behavioral variables
    - 3.6.3. Detailed taxonomy of system variables
  - 3.7. Response
- 4. Social
    - 4.1. Culture
    - 4.2. Politics
    - 4.3. Economics
    - 4.4. Resources
    - 4.5. Group characteristics
    - 4.6. Confinement
    - 4.7. Isolation
  - 5. Equipment
    - 5.1. Personal
    - 5.2. Personnel
    - 5.3. Physical characteristics
    - 5.4. Requirements
    - 5.5. Logistics
    - 5.6. Input/output

